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of the

American Association *of* Petroleum Geologists

AUGUST
1926

JOHN L. RICH
EDITOR

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THE BULLETIN

of the

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JOHN L. RICH, *Editor*

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Vol. 10 AUGUST 1926 No. 8

CONTENTS

OIL AND GAS FIELDS OF THE TEXAS PANHANDLE 733
By C. Max Bauer

PREDICTIONS OF THE FUTURE OF OIL POOLS BY EARLY WELLS . . . 747
By Willard W. Cutler, Jr.

A CONTRIBUTION TO THE GEOLOGY OF LOS ANGELES BASIN, CALIFORNIA 753
By J. E. Eaton

SUBSURFACE CRETACEOUS SECTION OF SOUTHWEST BEXAR COUNTY, TEXAS 768
By Richard A. Jones

AN INTERESTING EXAMPLE OF A SURVEY OF A DEEP BORE HOLE . . 775
By F. S. Hudson and N. L. Taliaferro

THE SUBDIVISION OF THE ENID FORMATION 786
By F. L. Aurin, H. G. Officer, and Charles N. Gould

OIL POSSIBILITIES OF THE BLACK HILLS REGION 800
By. E. G. Sinclair

GEOLOGICAL NOTES
Fort Scott–Wetumka Correlation, *Edward Bloesch* 810
Combined Geologic and Oil-and-Gas Map of Wyoming 812
Notes on the Age and Correlation of the Moreno Shale, *J. A. Taff and G. D. Hanna* 812

THE ASSOCIATION ROUND TABLE
Appointment of Business Manager, *Alex W. McCoy* 815
Committees for the Autumn Meetings of the Association 815

AT HOME AND ABROAD
Current News and Personal Items of the Profession 817

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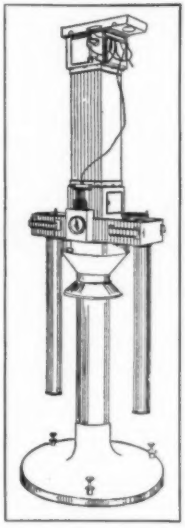

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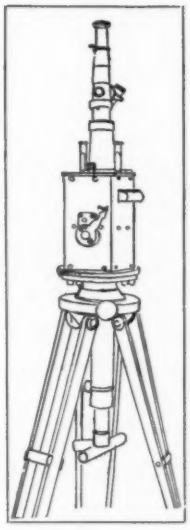

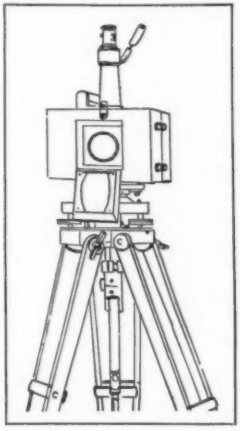

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1926

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AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST 1926

OIL AND GAS FIELDS OF THE TEXAS PANHANDLE[1]

C. MAX BAUER
Chief Geologist, The Midwest Exploration Company

ABSTRACT

The geology and development of oil and gas in the Panhandle anticline in the Panhandle of Texas are outlined in general terms. The anticline, which is approximately 100 miles long, is caused, in the writer's opinion, mainly by compacting of Permian sediments over buried mountains of igneous and metamorphic rocks. Gas is found in Permian limestone along the axis of this structure for almost its entire length. Oil is found in two formations on the north flank: One of the oil sands is an arkose called locally "granite wash," which occurs in patches in an inner belt near the buried hills; the other oil sand is a dolomitic limestone, which carries gas on the top of the structure but oil in an outer belt which parallels, roughly, the main axis. The consistent low pressure in the oil and gas sands is discussed, and other features such as the position of the water table, faults and group correlations are also treated briefly.

INTRODUCTION

The Texas Panhandle has attracted renewed interest because the bringing in of several large wells seems to indicate the presence of a widespread oil-bearing area comparable in size to the known gas area in that region.

The completion by the Marland Oil Company, early in May of last year (1925), of a 600-barrel well in Carson County, followed by the increased production in Hutchinson County due to the Dixon Creek wells, and the well of the Twin Six Oil Company producing at the rate of 400 to 800 barrels per day have been responsible for this interest.

Although gas was discovered in Potter County in December, 1918, and oil in Carson County in May, 1921, yet development of

[1] Published by permission of the Midwest Refining Company.

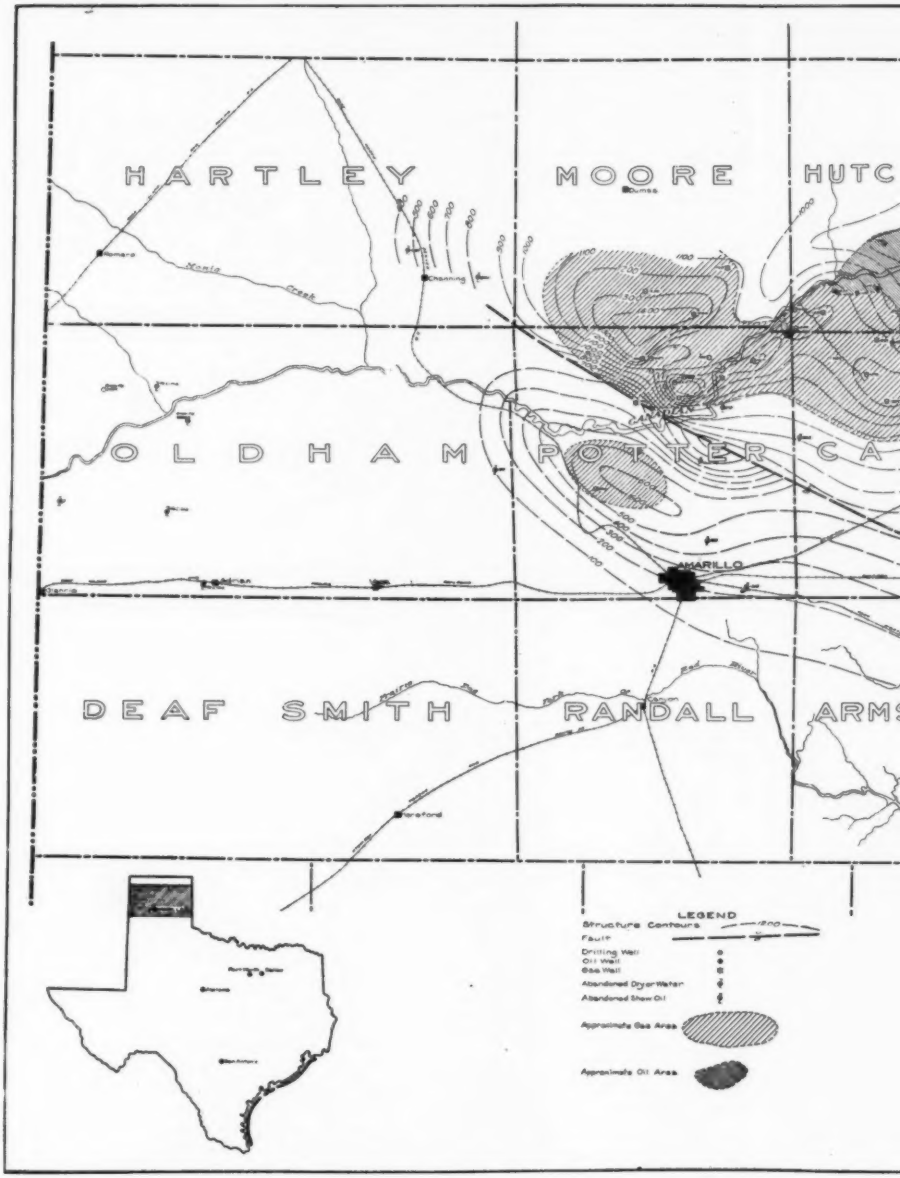
this district has been slow for a number of reasons. First, perhaps, is the lack of adequate market facilities; second, the cost of drilling the wells; third, the character of the oil, which congeals at a fairly high temperature; fourth, the general low pressure in the sands which does not produce spectacular wells; and fifth, a lack of understanding or appreciation of the geological conditions. It may also be said that a combination of these conditions, together with production problems involved, has caused a misunderstanding of the value of the field.

A search for surface geology which would explain the presence of oil has been largely fruitless, although it is granted that the first gas well was located on geological advice, on a large dome which can be mapped from surface exposures. However, the great size of the structural features which control the accumulation of gas and oil in this region has been baffling to many operators, and the tendency has been toward conservative estimates of the field, if not toward pessimism. The hypothesis put forth by Powers[1] in 1922, and favored by Pratt[2] in his paper on the Panhandle in 1923, that the structure in this region is due to the compacting of sediments over buried hills, or islands, of crystalline rock, forming a more or less continuous chain running northwestward from the Wichita Mountains for 100 miles or more, is now accepted as fact. The suggestion made by Harrison[3] that the doming or folding in the Panhandle was caused by intrusions of Permian or Pennsylvanian age, is untenable, in view of present evidence. Many kinds of rock have been found along the crest of this buried chain, ranging from igneous felsites, trachites, and diorites to metamorphic schists, gneisses, serpentine, and marble. This indicates, in the writer's opinion, that the series is of pre-Cambrian age, was elevated in early Paleozoic time, and existed as an archipelago in the early Permian sea. The lack of evidence of diastrophism in this general region since Permian time is well known, and the structure is similar to that which is found along the Nemaha Mountains in eastern Kansas, rather than

[1] Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Econ. Geol.*, Vol. 17 (1922), p. 233.

[2] Wallace E. Pratt, "Oil and Gas in the Texas Panhandle," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 237–46.

[3] T. S. Harrison, "Porphyry at Amarillo," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), pp. 434–39.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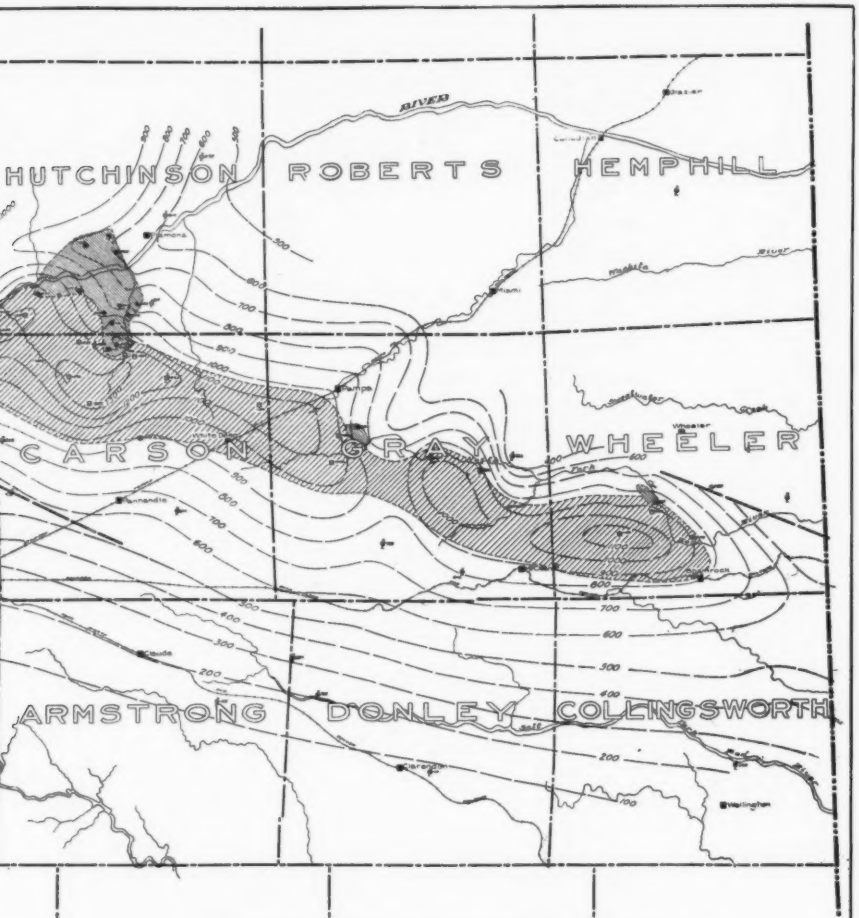

PANHANDLE OIL AND GAS FIELD
TEXAS

By
C. MAX BAUER
October 1925
Contours On Top Of Lime Series

like that in the Rocky Mountains. The Permian salt basin of Western Kansas, western Texas, and eastern New Mexico extends over this area. Such folding as has taken place since Permian time is evidenced only by the absence of Dakota and Comanchean strata from the vicinity of the Panhandle anticline.

In general terms, a large anticlinal structure extends from near the Oklahoma line in a northwestward direction across Wheeler, Gray, Carson, and Potter counties (Plate 27). This anticline carries gas along its crest throughout a distance of 90 miles or more. On the north flank of this structure oil has been found in these same strata. The formations producing gas and oil are of Permian age, and a typical well log for the district reveals the following groups of strata: The first 800 feet consists of red sandstone, red shale and gypsum. From 800 feet to 1,800 feet is a large amount of salt, interbedded with gypsum and red beds. From 1,800 feet to 2,100 feet, depending on the elevation of the location, is red shale interbedded with thin limestone and anhydrite streaks, at which point the top of the big lime series is encountered. From 2,100 feet to approximately 2,900 feet we have a series of non-red limestone, shale, dolomite, and anhydrite beds, known as the "big lime" series, which are predominantly blue, gray, or white. From 2,900 feet to about 3,075 feet is a shale zone containing streaks of lime and anhydrite. At this point is the granite wash, which lies in patches along the flanks of the structure but which is not present at a distance of three or four miles from the underlying pre-Cambrian masses. Below this we have again a white limestone which may possibly be the equivalent of Pennsylvanian elsewhere.

The gas is found in the big lime series at a depth of from 2,400 feet to 2,900 feet in southern Hutchinson County and at a lesser depth in Potter and Carson counties. The heaviest gas is usually found at about 2,700 or 2,800 feet. Likewise, this belt produces the largest oil wells when far enough from the axis of the major structure to be at the proper elevation.

In the area of development, oil wells in the granite wash may be expected in a belt paralleling the structure where the top of the big lime series is encountered at an elevation of from 1,250 to 1,100 feet above sea. Oil wells in the dolomite may be expected in a belt where

the top of the big lime series is encountered at an elevation of 950 to 700 feet above sea. Between the contours of 1,100 and 950 is a zone where small oil wells may be obtained, but the strata in this zone are not sufficiently porous to supply large wells. Everywhere in the Carson-Hutchinson County field water is found in porous strata when a sea level depth is reached. In some cases water has been obtained in wells 20 feet above sea level, but never, up to this time, has permanent water been found in the field between a depth of about 1,100 feet and this point.

STRATIGRAPHY

Formations exposed in the Panhandle district from the younger to the older are: Recent wind-blown sands and river alluvium; Tertiary sands and gravels, partly cemented with lime or gypsum, called "caliche"; Triassic sandstone, known as the "Trujillo"; and a shale and sandstone formation called the "Tecovas". Below this lies the Permian Quartermaster, red shale and sand, near the top of which is found the Alibates dolomite. Below this, the Cloud Chief red beds with some gypsum and the Day Creek dolomite (Fig. 1).

The surface of the high plains is underlain by 150 feet to 200 feet of sand and gravel of Pliocene age. (*Equus* bones have been found in these strata and pronounced of Pliocene age by J. W. Gidley.) This material was spread out over the area in late Tertiary times by streams and has since been partially cemented with secondary lime or caliche. The lower part of this group of beds, which is usually gravel, is the main water bearing horizon of the high plains. This gravel carries eroded fragments of shells (*gryphea*) from the Comanchean deposits which underlie it on the plains farther south and also farther north in the Oklahoma Panhandle. Along the Panhandle anticline the Comanchean and Dakota have not been found.

The valleys of the main streams such as the Canadian and North Fork of Red River are entrenched or eroded through the Tertiary cover into the Triassic and Permain beneath. The Triassic is exposed in Potter County and Oldham County, and the Permian in Potter County and eastward. The thickness of the Triassic is about 150 feet, in Potter County, being thicker to the west, but along the Canadian River northeast of Potter County the Triassic is missing,

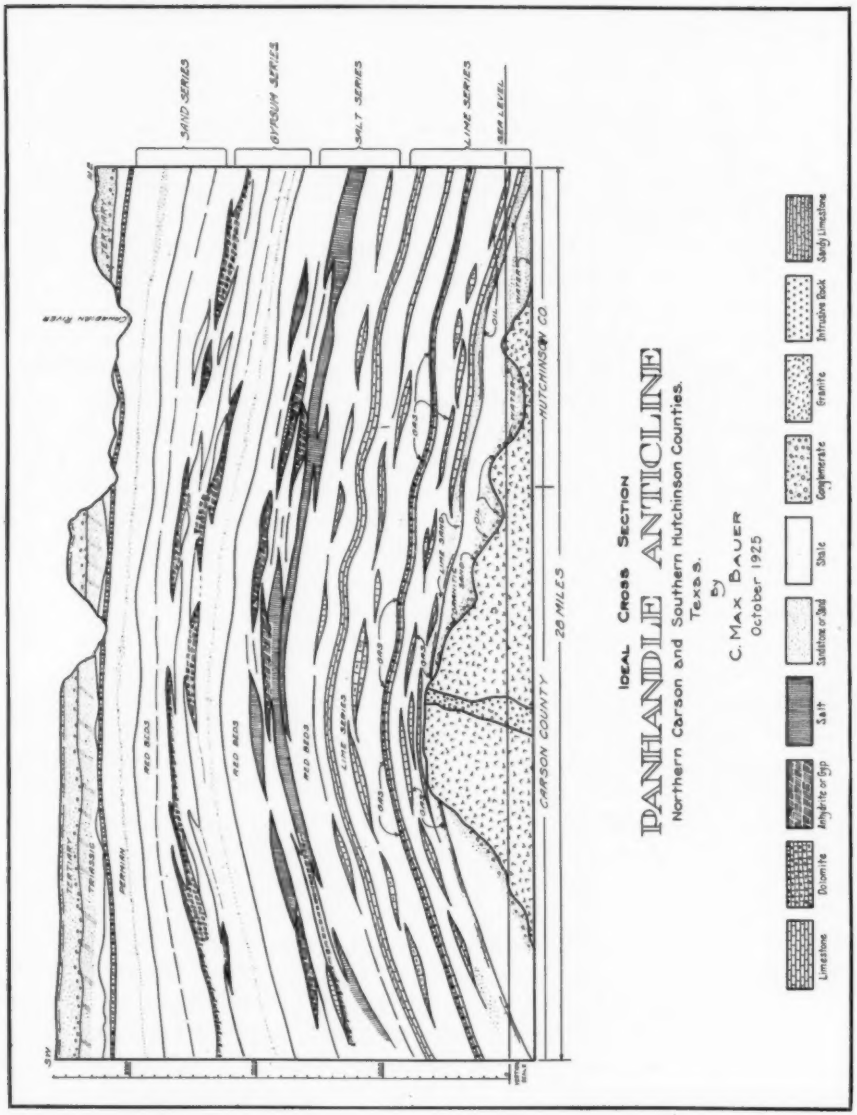
IDEAL CROSS SECTION
PANHANDLE ANTICLINE
Northern Carson and Southern Hutchinson Counties, Texas.
By
C. MAX BAUER
October 1925
SAND SERIES
GYPSUM SERIES
SALT SERIES
LIME SERIES
SEA LEVEL
CARSON COUNTY
HUTCHINSON CO
28 MILES
Limestone
Dolomite
Anhydrite or Gyp
Salt
Sandstone or Shale
Shale
Conglomerate
Granite
Intrusive Rock
Sandy Limestone

FIG. 1

and it does not appear in any of the exposures in Carson, Gray, or Wheeler counties.

Two large domes, which can be located from surface exposures, are John Wray and Four Six. These have been mapped on the Alibates dolomite which lies near the top of the Permian. This dolomite consists of two beds separated by about 10 feet of red shale. The upper member is from 5 to 10 feet thick and the lower member from 1 to 2 feet thick. Its structure is complicated by slumping and flowage of the shales beneath it, but the larger structural features are well depicted by it at the surface. This member disappears beneath the surface along the Canadian valley in eastern Hutchinson County and does not appear farther east. In Wheeler County only the lower Quartermaster, Cloud Chief, and Day Creek are at the surface and these are largely concealed beneath recent sand dunes and alluvium. The lower Quartermaster consists of alternating red sand and red shale, with thin streaks of gypsum. Its total thickness is about 300 feet. Below it the Cloud Chief is made up of about 500 feet of red shale, sand, and fairly thick beds of gypsum or anhydrite. Below the Cloud Chief is the Day Creek dolomite which is exposed near Shamrock and, though not traced by the writer, probably extends over a considerable area in Wheeler County.

The formations drilled through in the Four Six dome are representative of stata along the crest of the anticline. They are as follows: red beds, quicksand, sandstone, and clay for the first 500 feet or so; then another red group 500 feet thick in which dolomite and gypsum are conspicuous; followed by red beds containing varying thicknesses of rock salt, usually in several beds and aggregating as much as 300 feet in some cases; then red beds, with alternating thin layers of gypsum, anhydrite, and limestone which continue to a depth of 1,500 to 2,200 feet, below which the so-called "big limestone" is encountered.

The big lime is in reality a group of limestone, anhydrite and dolomite strata interbedded with light blue or pale green shale beds. The average thickness of this limestone series is about 800 feet. However, it is thicker to the north and to the south of the anticline than it is along the main axis. It also fingers out into shale toward the east quite rapidly, forming a big blue shale group with thin

limestone beds in it. In the writer's opinion it correlates with the big blue group of the Kansas Permian. Toward the west it also changes to shale quickly, and only group correlations of strata are possible at this time.

Throughout the 800 feet of limestone section fossils of any sort seem to be very scarce. In addition to the shale there are many streaks of anhydrite and dolomite which seem to lens out and in, in short distances. At the base is a 200-foot zone which contains much dolomite and some oölite in strata up to 18 or 20 feet in thickness. This is the main gas-producing zone and also the oil-producing zone in the Hutchinson County field. It also produces oil in Wheeler County, though the zone is only about 120 feet thick at that locality and does not seem so porous. While this zone is the important oil- and gas-bearing reservoir in the Panhandle anticline and it may be stated that at least 35 per cent of this zone is sufficiently porous to carry oil, yet the writer is not prepared to make any detailed correlations of the porous streaks within this zone. Below the dolomite is a gray shaly zone from 150 to 175 feet thick which, like the lime above, contains much anhydrite.

Beneath these shale beds the wells near the axis of the structure encounter minor thicknesses of red and blue shales alternating with arkosic sands consisting of fairly sharp fragments of quartz and feldspar, and minor portions of hornblende and other minerals. This section applies very closely to Gray and Wheeler counties, with the exception that the upper Permian is thinner toward the east due to erosion and the lime series contains more shale and less lime.

The arkosic sand and conglomerate varies in thickness from a few feet on the tops of the major domes to 250 feet or more down on the flanks, and in many places rests on fresh crystalline or metamorphic rock. It is thickest in the embayments and missing in some wells four or five miles from the ridge. It also carries a large percentage of lime away from the axis. Several wells on the flanks of the main anticline drilled through as much as 50 feet of coarse arkosic sand and bowlders and penetrated limestone and shale beneath. Holmes' No. 2 Morse, in Gray County, encountered black shale and coal beneath granite wash; and the Prairie Oil and Gas Company's

No. 1A Farwell, in Hartley County, encountered a change of formation at 4,275 feet and from that point to the bottom of the hole at 5,010 feet drilled through "dark lime and black slate" which may correlate with the Magdalena limestone of New Mexico.

BURIED ISLANDS OF IGNEOUS ROCK

The existence of buried hills or islands of granite or other hard rock is not new, but its significance with regard to oil has been appreciated only since 1916 when granite was encountered in drilling wells along an anticline in central Kansas.[1] This buried granite ridge was found to extend from the Eldorado field northeastward through Cottonwood Falls, Zeandale, Seneca, to Table Rock, Nebraska. The main producing oil fields lie on the south end of this ridge at Augusta and Eldorado, Kansas, where the granite is quite deep and the Stapleton sand at Eldorado is in reality composed of detritus from this ancient ridge. Other pools were found along the west side of the ridge at Potwin, Peabody, and Florence, Kansas. The deep sand at Healdton, Oklahoma, has been found to lie around a buried island of Arbuckle limestone.[2]

The main significance of these buried ridges and hills lies in the manner in which the overlying sediments were arched by unequal settling rather than by lateral compression or regional diastrophism and also in the origin, extent, and character of the sands which form the oil reservoirs. In most cases granitic sand bodies do not appear to extend over the highest parts of the buried hills but rather to lie about their flanks, and are thickest in re-entrants. The highest por-

[1] C. H. Taylor, "The Granites of Kansas," *Southwestern Assoc. Petrol. Geol. Bull.*, Vol. 1 (1917), pp. 111–26.

Sidney Powers, "Reflected Buried Hills and Their Importance in Petroleum Geology," *Economic Geology*, Vol. 17 (1922), No. 4, p. 233.

A. E. Fath, "The Origin of Faults, Anticlines, and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Surv. Prof. Paper 128 C*, 1920.

[2] R. C. Moore, "The Relation of Mountain Folding to the Oil and Gas Fields of Southern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 1, pp. 32–48.

John G. Bartram and Louis Roark, "The Healdton Field, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 4 (1921), pp. 469–74.

George E. Burton, "Relation of the Base of the Red Beds to the Oil Pools in a Portion of Southern Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (1921), pp. 173–77.

tions of the buried granite or other crystalline rock have been swept clean of sand and other porous material and the embayments are filled with the outwash either by streams or by wave action along ancient shore lines.

The facts gathered from the wells drilled on the Panhandle anticline indicate clearly the existence of at least seven buried masses of igneous and metamorphic rock over which the sediments, after deposition, have compacted and settled, causing domes which are more or less connected into an anticline of enormous size extending from the Wichita Mountains in Oklahoma northwestward across the Texas Panhandle to eastern Hartley County.

Another buried hill which should be mentioned is known as the Bravo dome. It is in western Oldham County. This dome has been drilled at several points and granite reported as shallow as 2,300 feet, but it has not been sufficiently prospected to say whether oil is present on its flanks or not. However, the stratigraphy in this area is not so promising.

FAULTING

An outstanding fact regarding the Panhandle anticline is the presence of two large faults which have been located by subsurface data. One has been traced from the northwest corner of Potter County southeastward to the vicinity of Conway in southern Carson County. This fault has the downthrow on the southwest side with a maximum throw of about 1,400 feet in the Lower Permian, dying out toward the surface, with no evidence of faulting in the Triassic strata which are found crossing this fault at the surface. There is some doming south of this fault in the vicinity of Gentry, about ten miles northwest of Amarillo, as shown by several gas wells in this locality.

The other fault is probably of equal magnitude and also runs in a northwest-southeast direction, being fairly well defined in central Beckham County, Oklahoma, and running northwestward between the Shedden-Emler well and the Skelly-Davis well of Wheeler County, Texas. This fault has a downthrow on the northeast side with maximum displacement of well over 1,000 feet in the Lower Permian, also dying out toward the surface. The writer does not know if there is any evidence of faulting at the surface in this trend

or not. These faults are doubtless much greater in the pre-Cambrian than in the Permian and reveal the structural inclinations of the basement rocks of this region, which caused these ancient mountains.

These faults explain in large measure the westward extension of the Anadarko basin and the Canadian trough of central Potter County.

The accompanying diagram (Fig. 1) is an ideal cross section of the Panhandle anticline from southwest to northeast in the vicinity of the Carson-Hutchinson County field, along a line where faulting is apparently absent.

THE OIL-BEARING SANDS

As stated earlier in this paper, the porous strata in the big limestone series are filled with gas all along the higher portions of the major anticline. To date, with two exceptions, the oil has been found along the north flank of the anticline in sandy dolomite in the lower part of the lime series, and in granitic sands and gravel beds beneath the big lime. One exception is a good showing of oil in the Culberson No. 1 well in central Carson County, south of the axis. The other is a showing of oil in the Silk-Medley well in southern Gray County.

The oil sands vary from several feet to 60 or 80 feet in thickness. The granitic sands appear to be thickest in slight embayments or depressions extending northward from the axis as much as 4 or 5 miles in places and skirting around the granite islands much as beach sands might, suggesting that if they were stream deposited they were doubtless reworked by the early Permian sea. However, the sands which the writer has examined consisted of coarse grains of quartz and feldspar that are only partially rounded. Some of the grains are quite angular, with only a small amount of cement and indicate high porosity. The outward limits of these sands carry water. The water level, by coincidence, follows within 20 feet of present sea level. That is, the present water level on the north flank coincides very closely with sea level.

The granitic sands which produce oil mainly in Carson County contain very little cementing material; they are coarse, carrying pebbles as large as a pea, and, there is reason to think, also bowlders

of considerable size; they are lenticular and probably overlap each other though they are doubtless elongated parallel to the ancient shore lines and were probably formed at successive stages by the encroaching sea. Because of the coarseness and angularity of the grains, the sands are believed to be the result of wave action which would form beach ridges and wave-built terraces. Other bodies of sand may have been formed by shore currents into bars, spits, and hooks, and still other portions may be residual.

The lime sand, which is in reality a porous dolomite containing as much as 50 per cent of anhydrite, lies about 150 feet stratigraphically above the zone of granitic sands. This zone of dolomite is approximately 200 feet thick. It is a sheet deposit and extends fairly regularly for long distances. There are several porous layers which vary from 15 to 30 feet in thickness so far as known. One layer is decidedly oölitic, whereas another contains openings like a sponge. They are filled with gas on top of the structure and on the flanks for several miles from the axis. Most of the wells producing out five miles or more from the axis are making oil from this sand. Still farther out it carries water.

PRODUCTION

GAS

The Texas Panhandle now has a daily capacity of approximately 1,500 million cubic feet of gas and a proven area of 325 square miles of gas territory. This capacity has been estimated from between 50 and 60 producing gas wells, and does not include gas shut in, in oil wells. There are 25 or 30 more wells that were drilled through strata carrying great quantities of gas, but were mudded off and their capacity is not known.

The most accurate figures were obtained from Potter County, where a recent gauge has been taken of 20 gas wells controlled by the Amarillo Gas Company. These wells are from six months to five years old and show little decline from the original estimate on the average, but several wells which were doubtless estimated high to begin with are now off about one-third. Of course, the present consumption of gas from these wells of about 10 million cubic feet per day is not great enough to materially effect a decline. Some of the wells actually gauge more now than three years ago.

The total capacity of these twenty wells gauged on October 5 and 6, 1925, is 334,576,000 cubic feet per day, or an average of 16,725,000 cubic feet per well.

Wells in Carson and Hutchinson counties show a higher daily average than those in Potter County, but these wells are now used only for fuel in drilling other wells.

The pressure in all of the wells is very much the same, ranging from 420 pounds per square inch to 460 pounds per square inch, and according to records of wells taken in the early days of the field, this pressure has not declined since the first well was brought in, in December, 1918.

The gas occurs in the Lower Permian strata at a depth of 1,600 to 2,400 feet along the crest and 2,900 feet down on the flanks. It is found in dolomite, interbedded with thin limestone and anhydrite. The first gas is usually found about 320 feet below the top of the big lime series, and at intervals from this point on down through a section of limestone for 500 feet. From three to seven gas sands are penetrated before the oil horizons are reached. The thickness of the gas pay sands varies considerably in different wells but the total porous reservoir strata will average about 200 feet. The uniform pressure of the gas from top to bottom and in various parts of the field suggests communication between the strata and over a wide area.

OIL

The oil of the Panhandle is very similar throughout the district. It ranges from 34 to 37° Bé., and congeals at 50° F. An analysis of an average sample is given below:

Gravity	35.5° Bé.
B.S.	.4 per cent
I.B.P.	80° F.

The oil lies in a horizontal zone on the water table which is at sea level or within 20 feet of sea level throughout the field. The upper limit of this oil zone is about 200 feet above sea level whether the oil is found in granitic sands or dolomite. Since the water table is comparatively static, the gas is considered the active agent in the expulsion of the oil from the sands; and it is the writer's opinion

that when the wells play out there will be more of them going to gas than to water. Hence the decline of these wells is not rapid at first and the curve of decline is more nearly a straight line than the usual decline curve.

The fact that the oil congeals at a relatively high temperature causes trouble in transportation, and the high wax content causes trouble in the parafining of the sands.

However, the thickness of the oil sands and the size of the area indicated by the drilling to date forecast a long-lived field which will produce a great quantity of oil.

TABLE I

Product	Percentage	Gravity	I. B. P.	Max.	Flash	Fire	Percentage at 410° F.
Gasoline	27.0	52.5	168	448	.....	.....	93.5
Kerosene	12.0	41.3	394	.....	165	190	5.0
Gas oil	25.0	34.5	.....	.....	235	270	.....
Wax dist	25.0	30.7	.....	.....	260	305	.....
Bottoms	9.0	14.0	.....	.....	.....	.....	.....
Loss	2.0	.....	.....	.....	.....	.....	.....

Three crude-oil pipe lines now extend from the railroad to the Carson-Hutchinson County field and one line from the railroad to the Wheeler County production.

The production of the Carson-Hutchinson field at the present time is approximately 10,000 barrels per day; from Gray County, 600 barrels per day; and from Wheeler County, 200 barrels per day.

PRESSURE IN THE OIL, GAS, AND WATER SANDS

Among other peculiarities of the Panhandle field one characteristic is perplexing to the geologist and operators alike. It is the subnormal pressure. This pressure is consistent over a large area, being approximately 450 lbs. per square inch in the Potter County gas field, in Carson, Hutchinson, Gray, and Wheeler counties, in the big lime series and the arkosic sands alike.

The uniformity of the pressure suggests communication between the porous strata and widespread porosity, in certain strata at least. This the writer believes to be due to communication along the unconformity between the Permian and the pre-Cambrian. There is

undoubtedly sufficient coarse material along this contact which traverses the various strata involved to cause equalization of pressure.

The low pressure of the sands is tied up closely with the present water table in the Permian which is very close to sea level. No permanent water has been reported in the field between a depth of about 1,100 feet and 2,900 feet. The upper and lower limits depend on the elevation of the surface at the hole. The pressure is about half the normal hydrostatic head when sea level is reached. The first consideration is that although these strata were deposited in water and were doubtless filled at one time, they have, at least for a long period, lacked an adequate source through intake. As stated before, the porous strata of the big lime series pinch out to the east and to the west and do not outcrop at any place, known to the writer, that is higher than their elevation in this district. Hence, the source of supply and hydrostatic head are missing. What then has caused the receding water table and diminishing pressure? One suggestion will be made: Much anhydrite exists in the section, which in places is changed to gypsum. Has some of the anhydrite taken up water, thus changing to gypsum and depleting the supply, thereby lowering the water table in these strata and at the same time lowering the pressure?

March 20, 1926

PREDICTIONS OF THE FUTURE OF OIL POOLS BY EARLY WELLS[1]

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ABSTRACT

The value of using both geological information and production data for predicting the future of newly producing oil pools is discussed. For such estimations the author advances a method which consists of selecting that developed pool of the district which has conditions most similar to those of the newly discovered area, and then modifying the average production decline curve, the average ultimate production per acre, and the productive acreage of the older pool to meet these new conditions. The limitations of such a method are discussed.

INTRODUCTION

Among the difficult tasks undertaken by the oil geologists has been that of estimating the future production of oil and gas. The pioneers who attempted this were often severely criticized and even ridiculed. But in 1919 the production decline curve method, as presented by J. O. Lewis, Carl Beal, J. L. Darnell, Roswell Johnson, Dan Nolan, Norval White, and others, was, under the direction of Ralph Arnold, described in the *Manual for the Oil and Gas Industry* of the Treasury Department. Since that time it has been generally recognized that this method, when properly applied to properties for which a production decline curve can be formed, is more reliable and gives more satisfactory and complete estimations than any other method as yet advanced.

The production decline curve is a pressure-volume curve which is controlled by a combination of all of the natural and artificial factors which affect an oil well. It is formed from past production records and is used as the basis of estimations when producing conditions are to continue in the future as they have in the past. But, unfortunately, in a new pool there are no past production records to extend, nor is there any known method of constructing a production

[1] Read before the American Association of Petroleum Geologists, November 20, 1925.

decline curve from a knowledge of the conditions relating to the production of a well.

Predictions for properties in pools just proved by the drill are usually made either by the barrels-per-acre method or Washburne's saturation method. These two methods furnish preliminary and rough estimations but do not give the rate of recovery, knowledge of which is most vital for formulating policies of development.

This paper outlines a method of constructing a tentative average production decline curve for a new pool by analogy with the most similar old producing pool known and discusses the limitations of such a method. This paper does not outline the procedure for making estimations after the average curve of the new pool has been obtained, as that has already been described thoroughly in numerous publications, both government and otherwise.

The writer wishes to thank James O. Lewis and Roger White for their helpful criticisms of this paper.

VALUE OF EARLY ESTIMATIONS

It is during the initial life of a pool that the most important financial decisions must be made. These include the outlay of capital warranted, the acquisition of nearby acreages, the rapidity of development, spacing of the wells, laying of pipe lines, erection of plants, and the marketing of the oil and gas.

Estimations made to outline such policies must be as reliable and accurate as possible and, therefore, should be based upon the greatest number of important available facts.

EARLY DATA AVAILABLE

The available facts bearing on the future production of new pools should include those concerning the local and general surface geology and topography; the underground geology, production data, and production curves of other pools; and the logs, cores or cuttings, and initial production data of the wells of the new pool itself. The more complete this information is, the more reliable the estimations should be.

The surface geology and topography usually aid in determining the type of structure and the shape and probable extent of the new

pool by analogy with old pools whose edges have already been defined.

The information regarding other pools should be sufficiently complete to decide what old pool is most similar to the new.

The cores and logs and the initial production data of the wells of the new pool should furnish information as to the depth, thickness, character, and correlation of the oil zone; casing and tubing pressures; rates of production of oil and gas; water cuts; gravity of oil; method of production; and mechanical conditions. This information must be the basis for selecting the similar pool to be used for comparison, and also for modifying the average curve of that pool in order to estimate the future of the pool in question. Foraminiferal and mineral content determinations for correlative purposes may prove invaluable.

METHOD OF PROCEDURE

Preparatory to selecting from producing pools the one which is the most similar to the area under consideration, tabulate those pools preferably in the same district which appear to resemble in their natural conditions the newly discovered area. In this tabulation include depths, thicknesses, textures, and ages of the oil horizons; initial productions of oil and gas; tubing and casing pressures; gravities of oil; types and extent of structures; probable drainage areas; and any other available data which bear on the subject. From this table, that developed pool which, as a whole, has its conditions most similar to those of the newly discovered area should be selected.

The problem of changing the average curve of the old pool to meet the conditions of the new resolves itself, first, into modifying it to meet the differences in the natural conditions; second, in determining the most economical spacing for the new pool; and third, in further adjusting the already modified curve to meet this probable spacing.

The chief natural differences which will probably be found to exist between the two pools will be the thicknesses and saturations of their oil zones. Under these circumstances, average wells of the two pools may differ greatly in initial pressures and initial and ultimate productions; but, nevertheless, their factors of production and pressure may be expected to have a somewhat fixed relationship to

each other throughout their lives. If this relation can be determined for any one period, the whole production decline curve of the older pool may be modified to conform to the natural conditions existing in the new pool.

To determine this relation, first plot the average production decline curve of the old pool selected, noting the casing pressures, shut in or otherwise, which occurred with various rates of production. If casing pressures are lacking, use tubing pressures, being careful to note the sizes of the orifices used. Due to lack of complete pressure records, interpolations will probably be necessary; in fact, in many cases only initial and present pressures are available. Read from this average curve of the old pool the daily production which occurred with the identical pressure recorded in the well or wells of the new pool.

To illustrate, assume that the average initial productions of the first wells of the new pool are 500 barrels of oil per day with casing pressures of 1,000 pounds to the square inch.

Also, assume that when the initial casing pressures of the first wells of the older pool had dropped to an average of 1,000 pounds per square inch, the wells were averaging 1,000 barrels of oil daily. With 1,000 pounds pressure, the wells of the new pool only produce 500 barrels of oil per day, but those of the old pool with that same pressure produced 1,000 barrels of oil per day. The ratio between the productions of such wells with equal pressures would, therefore, be as 500 is to 1,000, or as 1 is to 2.

To modify the average curve of the old pool to conform to the natural conditions in the new pool, according to this determined relationship, construct above or below the old curve a curve whose ordinates will bear to the ordinates of the old curve the same ratio as has been shown to exist between the productions of those wells of the two pools which had identical pressures, in the case of our illustration as 1 is to 2.

The newly constructed curve is the average production decline curve for the new pool with the same well spacing as exists in the old pool. But this spacing may not be at all the spacing which is desired or economical for the new pool, and spacing, as we know, affects very materially the declines and the initial and ultimate productions of

later wells. The curve should, therefore, be corrected for spacing, using the rule that the ultimate productions of wells of equal size in the same pool vary approximately (for spacings ordinarily used) directly as the square roots of the areas drained by the wells, and that the ultimate production per acre varies inversely as the square root of the areas drained by the wells. To do this, first determine the most economical spacing of the wells in the new pool and then change the production decline curve already obtained to agree with this new spacing.[1] The curve can most easily be changed by first constructing an appraisal curve which shows the relations between the estimated ultimate productions of average wells of various sizes in a pool, then changing this appraisal curve according to the spacing determined upon, and then forming the corrected production decline curve from this altered appraisal curve. The resulting curve will be the tentative average production decline curve of the new pool in which it is assumed production methods like those in the older similar pool will be used. If other production methods are to be employed, this tentative average production decline curve must be further modified.

From the final curve, estimations may be made of the probable life of the wells, the ultimate production per acre of areas to be drilled by varying programs, and the probable present value of the profits to be expected, using a stated price of oil. Allowances should be made for the facts that the later wells in drilled areas may be expected to have smaller initial, and, hence, smaller ultimate productions than the earlier wells, and that different parts of the field may vary in production. The possibility of faulting with its effect on production should be considered.

LIMITATIONS OF METHOD

The method described in this paper is applicable to pools in which the oil flows to the wells chiefly through the effect of the accompanying and included gases. Almost all of the production in the United States is of this type.

Obviously, as the basis of this method is an analogy between an

[1] The writer has described the effect of spacing and the method of determining the most economical spacing in the U. S. Bureau of Mines Bulletin 228, p. 105.

old and a new pool, the value of estimations thereby obtained depends primarily upon the similarity between the two pools and the reliability of the average curve of the older pool; therefore, a thorough knowledge of the geology, production data and curves of numerous old pools, and an accurate knowledge of the existing conditions in the new pool are essential to reliable estimations.

With close analogies, such estimations for new pools may be expected to be sufficiently accurate to formulate complete development policies; but, on the other hand, if the two pools being compared are in different districts, have different producing horizons, or represent dissimilar types of structure, or if there is a probability of faulting or of spotty production, the estimations thereby obtained will be less reliable. Estimations for areas in the same pool but distant from producing wells are, as with all other methods, more hazardous than those made for close-by tracts.

If the new pool shows appreciable amounts of water with the oil, sanding and heaving, or any other unusual features, estimations should be delayed, if possible, until the effect of these factors has been determined, or, in any case, until a representative well of the new pool has shown a practically constant rate of production during a period of at least several consecutive days.

In using this method, state clearly the depth of penetration of the oil zone for which the estimations are made. Do not attempt to estimate production for thicknesses of sands as yet not penetrated. However, it would be wise to refer to the amount of production obtained from deeper sands in other areas of the district and to state the probability of obtaining these productive sands in the pool in question.

The engineer using this method should not only be familiar with evaluation practices but should also have had considerable geological experience. Each case must be considered by itself, and it is difficult to describe exactly what should be done to meet different conditions because the procedure will be somewhat a matter of experience and judgment. This method is believed to be an improvement over former methods, inasmuch as it enables the engineer to make more complete and reliable estimations for newly discovered oil pools than before.

A CONTRIBUTION TO THE GEOLOGY OF LOS ANGELES BASIN, CALIFORNIA[1]

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ABSTRACT

As a contribution to the general geology of Los Angeles Basin, the stratigraphy, earth movements, and structure of the district are discussed. Formations previously described from separated localities are correlated for the basin as a whole, and certain sediments are subdivided into recently recognized divisions. It is concluded that the productive structure of the district is in part a result of stresses produced by differential horizontal movements which occurred in Pliocene and Pleistocene time.

INTRODUCTION

Los Angeles Basin is a highly cultivated and productive depression of about 1000 square miles lying between the Pacific Ocean and mountains to the north and east. Low hills and gentle swells due to anticlinal structure locally trend northwest across its surface. Much of the northern portion is occupied by the city of Los Angeles and suburban towns (Fig. 1).

Various published articles have dealt with local geologic phases, or particular oil pools, of Los Angeles Basin. A complete bibliography of these is beyond the scope of this paper, but certain works of Eldridge and Arnold[2] and Arnold and Loel,[3] which have been especially useful, are here acknowledged.

The writer is indebted to Ralph Arnold for the identification of fossils from the Vaqueros formation, to Paul P. Goudkoff for a similar service for the Fernando group, and to William S. W. Kew for constructive criticism of portions of the manuscript.

[1] Read before the San Francisco meeting of the American Association of Petroleum Geologists, November 20, 1925.

[2] George H. Eldridge and Ralph Arnold, "The Santa Clara Valley, Puente Hills and Los Angeles Oil Districts, Southern California," *U. S. Geol. Survey Bull. 309*, 1907.

[3] Ralph Arnold and Wayne Loel, "New Oil Fields of the Los Angeles Basin," *Amer. Assoc. Petrol. Geol.*, Vol. 6 (1922), pp. 303–16.

GEOLOGY

STRATIGRAPHY

The strata of Los Angeles Basin vary widely in different districts due to varying distances from the chief source of the sediments which, during the later half of Tertiary time, were derived largely

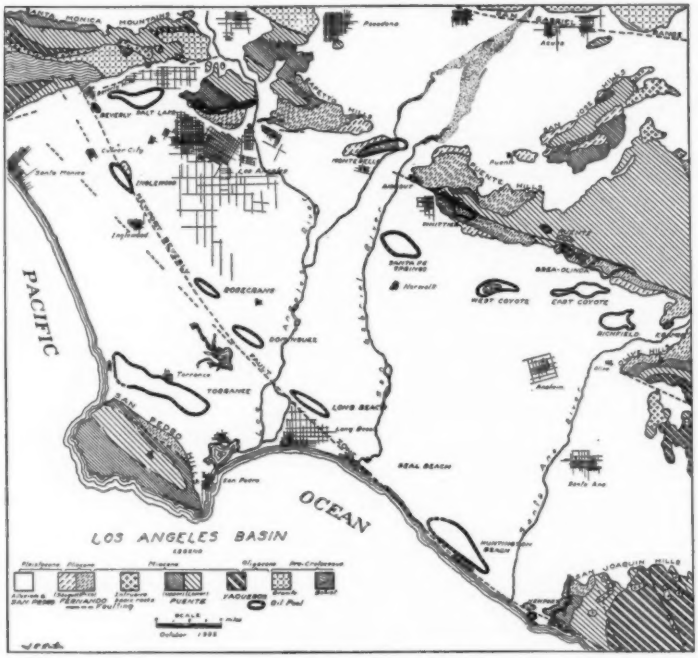

FIG. 1.—Geology and oil developments of Los Angeles Basin

from the north and east. Gravitational sorting has caused conglomerates of one locality to be represented by sandstones in another, sandstones to grade into shales, and vice versa. Thicknesses of the formations are likewise variable due to erosion, to unconformities above and below, and to faulting. There is also a thinning of the sediments basinward. These features, commonly combined with poor bedding, make detailed sections difficult to obtain.

A generalized stratigraphic column for Los Angeles Basin is presented in Table I.

TABLE I

STRATIGRAPHIC COLUMN, LOS ANGELES BASIN

Geologic Age	Formation		Thickness	Lithology
Recent				Alluvium and terrace materials
				Unconformity
Pleistocene	San Pedro group		500±	Sands and gravels (partly marine)
				Unconformity
Pliocene	Fernando group	Saugus formation	1400±	Conglomerates, sands, and blue clays (partly marine)
				Unconformity
		Pico formation	5600±	Sands and blue, brown and gray sandy shales. Locally conglomeratic (chiefly marine)
				Unconformity
Miocene	Monterey group	Puente formation	3200±	Diatomaceous shales with local sandstones and thin, brittle, calcareous layers (marine).—Intrusive basalt and diabase.—Heavy-bedded sandstones with interbedded sandy, siliceous, and diatomaceous shales, and locally a basal argillaceous lens (marine)
Oligocene (?)		Vaqueros formation	1000+	Coarse, massive sandstones; locally conglomeratic (chiefly marine)
				Unconformity
Pre-Cretaceous				Dark, micaceous schist intruded by granite

PRE-MONTEREY ROCKS

Schist (*pre-Cretaceous*).—In the Santa Monica Mountains on the north side of Los Angeles Basin, a dark schist is exposed which is intruded by granite. Its age is unknown except that it is Jurassic or older. Franciscan chert, schist, and sandstone of probable Jurassic age occurs in the San Pedro Hills.

Granitic rocks (*pre-Cretaceous*).—Diorite, and biotite and hornblende granites largely bound the basin upon the north and northeast. The latter have intruded the schist in the Santa Monica Mountains.

Cretaceous and early Tertiary Rocks.—Strata of Cretaceous, Eocene, and Oligocene (?) age are present in the Santa Ana Moun-

tains upon the east, and in parts of the Santa Monica Mountains to the northwest, of the basin's edges. They are not exposed in the basin proper.

MONTEREY GROUP

For a brief summary of Monterey time in the Coast province, the writer can do no better than quote A. C. Lawson,[1] as follows:

> Miocene time in the Coast Range region was characterized by a progressive subsidence with oscillations of the coast. The Miocene sea gradually transgressed the continental margin from the southwest and, as it did so, spread a formation of arkose sands and conglomerates over the greater part of the southern Coast Ranges. This was followed, as the water deepened, with progressive subsidence, by a remarkable deposit of bituminous shales.

Vaqueros formation (*Lower Miocene*).—The Vaqueros formation is the forerunner of a great organic series. It is the earliest and coarsest phase of a long period of conformable deposition and is the earliest extensive formation outcroping in Los Angeles Basin. The strata in various sections embrace from 1,000 to 2,700 feet of coarse, massive sandstones.[2] These sandstones are not uncommonly conglomeratic. Certain less massive phases are separated by layers of argillaceous shales. The rocks are soft, massive, and coarse in the Santa Ana Mountains on the east and become finer grained and harder southwestward in the San Joaquin Hills, due to mechanical sorting and cementing. White and gray colors in the southeastern part of the basin change northwest in the Santa Monica Mountains to reddish brown and buff. In the latter locality the formation, as mapped, may include younger beds which are in part equivalent to the Topanga formation farther west.

The Vaqueros formation is locally fossiliferous. It is chiefly marine, but upon the eastern border of the basin it grades into multicolored strata probably equivalent to a part of the non-marine Sespe formation of Ventura basin. In the San Joaquin Hills a typical Vaqueros fauna occurs near the top of the formation, indicating that thick, massive sandstones which lie below this are possibly of Oligocene age.

[1] A. C. Lawson, "Report of the Earthquake Investigation Commission on the California Earthquake of April 18, 1906," *Carnegie Inst. of Wash.*, Vol. I, Part I (1908), p. 9.

[2] The thicker sections probably include some Oligocene.

The following fossils, among others, have been found by the writer in the San Joaquin Hills and in the Santa Ana Mountains:

Arca osmonti Dall
Mytilus sp., probably *M. mathewsoni* Gabb
Ostrea eldridgei Arnold
Pecten bowersi n. sp.
Scutella fairbanksi Merriam
Trophon gabbianum F. M. Anderson
Turritella ineziana Conrad

Puente formation (*Lower, and possibly Upper, Miocene*).—The Puente formation embraces marine sediments ranging from coarse, heavy-bedded sandstones to the finest diatomaceous shales. It rests conformably upon strata of Vaqueros age and is overlapped unconformably by various horizons of the Fernando group. The formation yields few fossils, and the somewhat fragmental sections exposed show many variations in lithology and thickness, due to the proximity of uplifts, which make correlation difficult.

The type section, as described by Eldridge[1] from the Puente Hills, exposes a lower member of argillaceous and siliceous shales, a middle member of heavy-bedded sandstones separated by thin siliceous shales, and an upper member composed largely of shales of a diatomaceous and siliceous nature. The lower shale member appears to be a lens due to local conditions of deposition, as it is not certainly recognized elsewhere in the basin.

In the hills just east of Olive and south of the type locality, a large north-dipping monocline furnishes a nearly continuous section of Puente strata 1,600 feet thick which rests upon massive Vaqueros sandstone and is overlapped at various horizons by a basal conglomerate of the Fernando group.

A similar section is exposed east of Newport in the southern part of the basin. Here, however, the formation is finer grained, with its lower members more siliceous and the purer calcareous layers less abundant.

In the city of Los Angeles the entire formation is thicker and more arenaceous, due apparently to near shore conditions caused by the Santa Monica Mountains uplift. The lower portion is over

[1] *Op. cit.*, p. 103.

2,000 feet thick and is composed of heavy-bedded coarse, rusty-weathering sandstones separated by thin layers of predominately sandy and argillaceous shales. The basal strata of this member were considered by Arnold[1] to be possibly of Vaqueros age. Thin-bedded diatomaceous and siliceous shales are present above the lower member, but are here seldom pure, being generally a gray color from an admixture of sand and are interbedded with sandstones.

In the San Pedro Hills, which form an island-like area upon the southwestern side of the basin, distant from any large uplift, the

TABLE II

SECTION OF PUENTE FORMATION EAST OF OLIVE

	Feet
Argillaceous and poorly bedded diatomaceous shale which fractures conchoidally and carries thin limestones in its lower and soft sandstones in its upper portions	400
Soft, pure, and very finely laminated diatomaceous earth containing thin, brittle calcareous layers	240
Coarse, heavy-bedded sandstones separated by thin platy shales	360
Thin-bedded arenaceous and diatomaceous shales	250
Heavy-bedded calcareous sandstone	350
	1,600

formation is more homogeneous. A limited amount of coarse sandstones occurs at the base of the section, but diatomaceous and siliceous shales predominate.

The exposed Puente sediments are thus seen to vary horizontally, due to differing conditions of deposition. The formation as a whole consists of a thick lower portion of gray to rusty heavy-bedded sandstones with interbedded sandy and siliceous shales and locally a basal argillaceous lens; and an upper portion of predominately diatomaceous shales containing thin, brittle, calcareous layers and soft sandstones. East of Olive, and also east of Newport, the upper member locally carries a thin bed of poorly exposed conglomerate which apparently occurs between the underlying pure, fissile diatomaceous shales and the overlying poorly bedded and more argillaceous variety. The conglomerate, together with an apparent

[1] *Op. cit.*, p. 145.

overlap at the first-mentioned locality, indicates a possible unconformity near the top of, and within, the formation. This evidence is contra-indicated by a succession of thin, interbedded limestones east of Olive whose sequence appears to be unbroken.

It seems probable that thicker sections than any exposed exist in the deeper portions of the basin, and that diatomaceous shales of the Puente formation have been a source of oil.

POST-MONTEREY ROCKS

Fernando group.—The term "Fernando" was originally applied by Homer Hamlin[1] to beds above the siliceous shales skirting the sides of the San Fernando Valley, in Los Angeles County. It was subsequently used in southern California by Eldridge, Arnold, and Anderson,[2] as a term under which to group a great mass of undifferentiated sediments which follow the Monterey and supposedly equivalent series and which end with the severe Pleistocene orogenic disturbance.

As a result of recent detailed mapping, Kew[3] has divided the Fernando sediments at and near the type locality into the Pico and Saugus formations, separated by an unconformity. Both of these formations, together with the unconformity which divides them,[4] are present in Los Angeles Basin.

The Fernando strata of Los Angeles Basin aggregate 7,000± feet of sands, sandy shales, clays, and conglomerates which overlap various horizons of the Monterey group, the gap being represented

[1] In unpublished manuscript.

[2] See *U. S. Geol. Survey Bulletins 309, 321 and 322*, 1907.

[3] William S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753*, 1924, p. 69.

[4] The Fernando sediments have been subjected to considerable erosion over most of southern California. Their most complete section probably occurs northwest of Santa Paula in Ventura County where a large monocline is faulted down between the San Cayetano and South Mountain overthrusts. Sedimentation at this locality appears to have been almost continuous throughout Fernando time, the only break in 18,000+ feet of sediments being a very minor unconformity which marks the Pico-Saugus contact four-fifths of the way above the base of the section. This locality may expose strata which are not present at the type section of the Fernando group, and as the rocks are fossiliferous it seems to be an excellent place to secure a Fernando fauna of maximum range.

by a long, fairly quiet period of erosion. The most complete sections of the Fernando sediments in the basin occur in the Rapetto Hills east of Los Angeles, and in the Puente Hills just east of Whittier.

Pico formation (*Pliocene*[1]).—The rocks of the Pico formation are coarse on the northeast and become finer to the southwest, due to increasing distances from the chief source of the sediments. Conglomerates and sandstones upon the northeast grade southwestward into sands and sandy shales as the deeper portions of the basin are approached. Sandy shales and clays increase in volume until southwest of the Newport-Beverly Hills (Inglewood) fault zone the lower portion of the formation is shown by deep wells to have a paucity of porous sands, although thin, impure beds of a sandy nature are logged monotonously.

A fairly complete but poorly exposed and faulted section starts in the Rapetto Hills south of Lincoln Park and continues with offsets eastward to the west quarter corner of Sec. 34 T. 1 S., R. 12 W. This section exposes at its base 1,500 feet of thin-bedded sands and shaly sands, predominately yellowish brown in color, but locally gray due to diatomaceous material. Above these is a poorly bedded mass of white and gray shaly sands 600 feet in thickness containing impure diatomaceous layers. These rocks are followed by 3,500 feet of strata which reveal from bottom to top a gradation through first, brown shaly sands containing thin, hard, siliceous shells; second, alternating sands and sandy brown and blue shales; and finally, sands and sandy blue clays. This is the most complete Pico section available in Los Angeles Basin, although a thick, conglomeratic phase occurs just east of Whittier. Strata equivalent to the basal 2,000 feet of the Rapetto Hills section are exposed in the business district of Los Angeles city. They have been described by Arnold (*op. cit.*, p. 150), who listed from them a characteristic Lower Pliocene fauna.

The section given above (which grades eastward into conglomerates) is believed to be representative of the Pico formation in the

[1] A mass of indirect evidence indicates that thin-bedded sands and impure diatomaceous shales occurring below known Lower Pliocene fossils may be of Santa Margarita (Upper Miocene) age. Due to a lack of positive proof, such a correlation is left to the future.

more central parts of Los Angeles Basin, subject to local variations in lithology and thickness due to mechanical sorting.

The following fossils,[1] which also occur at the type locality[2] of the Pico formation, are a few of those known to be present in the lower Fernando sediments of Los Angeles Basin:

Arca camuloensis Osmont
Arca trilineata Conrad
Bittium asperum Gabb
Cancellaria tritonoidea Gabb
Crepidula princeps Conrad
Macoma nasuta Conrad
Metis alta Conrad
Nassa californiana Conrad
Pecten ashleyi Arnold
Pecten healeyi Arnold
Pecten oweni Arnold
Phacoides californicus Conrad
Phacoides nuttallii Conrad

Saugus formation (Upper Pliocene and Lower Pleistocene).—The Saugus formation is apparently everywhere unconformable with underlying strata in Los Angeles Basin, where at different localities it rests upon sediments of Pico, Puente, and possibly even Vaqueros age. It is composed largely of loose, reddish-yellow weathering conglomerates and interbedded soft sands which appear to be of non-marine origin, but in the deeper parts of the basin the lower portion of the formation contains impure and poorly bedded gray sands deposited under marine conditions. A 1,400-foot section is exposed north of Montebello, comprising reddish-yellow weathering conglomerates with interbedded sands and sandy clays. In the San Jose Hills a similar section, which occurs above a Pliocene fauna, is probably to be correlated with this formation.

Although the beds are largely a monotonous succession of conglomerates and sands, the basal members are more or less similar over wide areas in southern California. In the type section of the Fernando sediments in the San Fernando Valley (north of Los Angeles Basin), the Saugus formation has at its base a conglomerate,

[1] Mostly listed by Ralph Arnold. See *U.S. Geol. Survey Bull. 309*, pp. 107 and 152

[2] Kew, *op. cit.*, p. 77.

this being overlain by calcareous reefs which are followed in turn by white and gray sands. In Los Angeles Basin, a somewhat similar succession, which is subject to areal variations, occurs commonly.

The Saugus formation, in common with the Pico strata, becomes finer grained to the southwest, but rarely does it lose its detrital aspect; conglomerates, gravels, and sands with a few sandy clays being prevalent. The formation probably covers the more central and hidden portions of the basin in one continuous sheet, although wells have demonstrated its thickness over the more eroded domes to be slight.

Owing to the largely non-marine nature of the Saugus sediments in Los Angeles Basin, an adequate fauna from them has not been collected by the writer. Their correlation is in little doubt, however, due first to their unconformable position above strata containing known Pico fossils; second, to an apparent local angular discordance with Pico rocks; and third, to their close lithological resemblance to the type section.

San Pedro formation (Pleistocene) and overlying terraces.—The San Pedro sediments were deposited after a Pleistocene orogenic movement which involved all preceding rocks of the basin, and they have, therefore, suffered a comparatively slight amount of deformation. The formation name was originally used[1] to designate two locally marine members, but other members are present above these two. This entire group, together with three overlying terraces, and alluvium, covers most of the basin with a thin layer of sediments which hide the lithology and structure of underlying rocks.

REGIONAL CORRELATIONS

Geologists of California have not been in entire accord regarding the exact correlation of the Miocene series in different portions of the state. This circumstance has arisen first, through a paucity of fossils in the middle or "Monterey shale" division (which also contains extreme lithologic variations); and secondly, through the effects of local unconformities near the close of the epoch. In Los Angeles Basin the extensive post-Monterey unconformity, believed

[1] Ralph Arnold, "Paleontology and Stratigraphy of the Marine Pliocene and Pleistocene of San Pedro, California," *Cal. Acad. Sci. Mem.*, Vol. III (1903).

to be traceable from southern California to Puget Sound, interrupts the Miocene succession and divides the later half of the Tertiary period into two distinct groups of sediments. Those sediments which immediately precede the above-mentioned unconformity are of Lower, and possibly partly Upper, Miocene age. They have been described under the heading "Monterey group." The Cenozoic sediments which rest upon the post-Monterey unconformity but which precede the severe Pleistocene orogenic movement, are of uppermost Miocene (?), Pliocene, and lower Pleistocene age. They have been described under the heading "Fernando group." The Fernando group in Santa Clara Valley, Los Angeles County, has been divided by Kew[1] into two formations separated by an unconformity. The uppermost Miocene sediments mentioned, may constitute a smaller third division.

STRUCTURE

Los Angeles Basin is a comparatively small and deep depression bordered, in part, upon the north and east by faults whose movements have been predominately vertical. The rather remarkable subsidence which this small area has undergone may be gauged by noting that more than 11,000 feet of Miocene and Pliocene sediments are known, a thickness which represents only the remaining rocks.

The structure of the basin as it pertains to petroleum, bears little direct relationship to the primary system of faulting, but is closely associated with an apparently much later system of fractures that have had both vertical and horizontal throws and which strike from N. 35° W. to N. 65° W., diagonally across the basin. A number of the larger oil pools are so obviously in proximity to the faulting of this system that a close relationship appears to be indisputable. These pools prevailingly occur in lines parallel to long, comparatively straight fractures which trend southeast and northwest, being located upon short anticlinal folds arranged *en échelon*.

The anticlinal structures along these fractures are apparently a result of predominately horizontal movements in Pliocene and Pleistocene time, these movements having probably been con-

[1] *Op. cit.*, p. 69.

temporaneous with the general orogenic disturbances which occurred during those epochs in southern California. The theory that the more productive anticlines of Los Angeles Basin were formed as a result of predominately horizontal movement along deep-seated fractures was published by the author[1] in January, 1924, and has since been discussed by other writers.[2] The following description of the Newport-Beverly Hills fault zone is reproduced from the author's article as being representative of conditions in Los Angeles Basin:

> The Newport-Beverly Hills fault zone occupies a long and narrow strip extending like a scar from southeast to northwest across the basin. . . . . The structure extending from Newport to Beverly Hills is apparently dominated by a line of deep-seated faulting in consolidated rocks, this being evidenced by wells drilled, movements during historic time, and a characteristic topography. The relation of the secondary structure to such deep-seated faulting is demonstrable by simple experiments with plastic substances.[3] Although this faulting is known to reach the surface at certain localities, such surface expressions have relatively little in common with the anticlines along the uplift's strike, being, like these anticlines, secondary to deeper structure.[4] The movements along this zone appear to have been largely horizontal and to have occurred in almost straight lines in rigid material buried at great depth. The result of the . . . . attendant drag has been the arranging of the more unconsolidated sediments near the surface into short folds at an angle to the deeper movement and *en échelon*. . . . . This horizontal faulting in the basement rocks . . . . is probably the result of crustal adjustments which have resulted in a relative movement of the basin from southeast to northwest along the coast and from northwest to southeast upon the landward side.

The foregoing description, with modifications, applies to other portions of the basin such as the Puente Hills fault zone, but at this locality and elsewhere normal compression is an increasing factor

[1] J. E. Eaton, "Structure of Los Angeles Basin and Environs," *Oil Age*, December, 1923, and January, 1924.

[2] R. N. Ferguson and C. G. Willis, "Dynamics of Oil-Field Structure in Southern California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 5 (September-October, 1924).

[3] Take a glass lantern slide to represent a rigid basement and cut this in half to show a line of shearing. If one entire piece of covering such as tracing cloth is now stuck loosely over the two basement halves, a sliding of these with reference to one another will reproduce the phenomena described.

[4] See A. E. Fath, "The Origin of the Faults, Anticlines, and Buried 'Granite Ridge' of the Northern Part of the Mid-Continent Oil and Gas Field," *U. S. Geol. Survey Prof. Paper 128-c*, 1920.

due to the proximity of uplifts. In western Los Angeles city the nearby east-west Santa Monica Mountains uplift has caused the structures of economic importance to assume an approximately parallel position, but even here the Elysian Park anticline strikes northwest to the very base of the mountains.

A tendency of California anticlines to lie *en échelon* has been noticed by various geologists, and it seems probable that horizontal movements have had a larger rôle in producing secondary structure than has been suspected.

TOPOGRAPHIC EXPRESSION OF STRUCTURE

The structure of Los Angeles Basin is to a large extent outlined by topography. Major faulting is generally represented by escarpments and low elevations in line, but such expressions, in many instances, are so eroded and fragmental that they are not obvious. The productive domal structure discovered to date has been invariably represented by surface elevations, these ranging from the elongated hills at Dominguez and Long Beach, which closely follow sub-surface structure, to the low, scattered swells which faintly indicate the doming at Richfield and Huntington Beach.

SURFACE INDICATIONS OF PETROLEUM

Surface indications of oil in Los Angeles Basin locally occur, but these are not particularly impressive compared with other productive districts in California. The largest concentration occurs at the Salt Lake pool in western Los Angeles city, where a lake covering several acres was formed during Quaternary time by exuding petroleum. A few oil seeps southeast of the Elysian Hills and in the Puente Hills, together with one large seep under the ocean west of Redondo, complete the "live" evidence of petroleum.

An important indication is the commonly bituminous nature of the Puente-Pico contact where exposed. The occurrence of bituminous strata at and near this contact is of wide extent, although the deposits themselves are not ordinarily of large volume.

The central portions of the basin do not at present furnish any surface evidence of petroleum, except possibly gas, due to the enormous protective covering of sediments above the reservoir beds at these localities.

OIL HORIZONS

The more productive horizons of the domal pools are believed to occur in the basal part of the Pico formation, although less productive zones extend into higher and lower strata. (Fig. 2.) These horizons are rarely pure sands, being generally zones containing

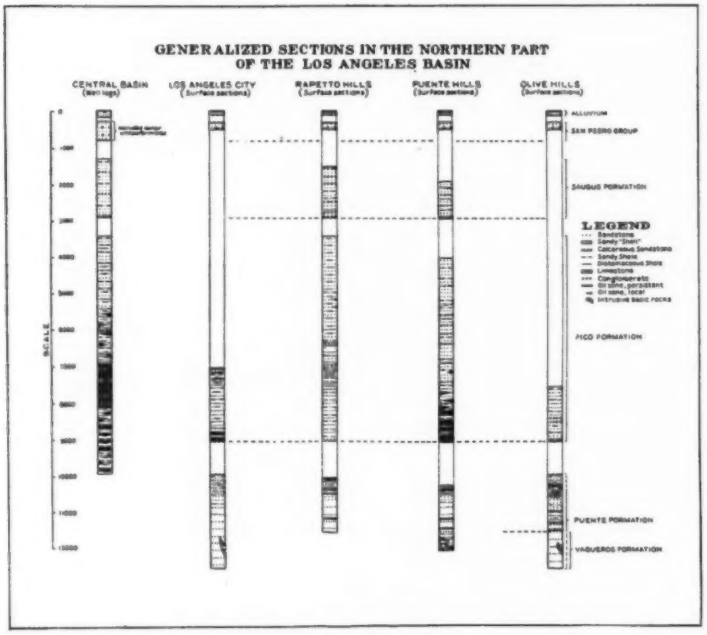

FIG. 2.—Generalized cross-sections in the northern part of Los Angeles Basin

several hundred feet of alternating thin-bedded shaly sands and sandy shales separated by thin, sticky partings. The productive horizons of those smaller pools which yield chiefly under monoclinal conditions[1] are comparatively pure sands just above or below the Puente-Pico contact.

[1] The small Puente oil pool is an exception to the above statement. This is apparently domal, and produces either from the base of the Puente or the top of the Vaqueros formation.

A series of productive zones totaling 2,000 feet in thickness is not uncommon in pools of Los Angeles Basin, and single wells at Long Beach have produced from this amount of strata. The total production of petroleum in the basin to and including August 31, 1925, has been approximately 813,167,000 barrels.

Data on oil production in relation to structure are summarized in Table III.

TABLE III

SUMMARY OF LOS ANGELES BASIN OIL POOLS

(AS OF AUGUST 31, 1925)

Pool	Dominant Structure	Productive Area	Productive Depths	Gravity Baumé	Total Production to Date
		(Acres)	(Feet)	(Degrees)	(Barrels)
Dominguez	domal	871+	3500–4300	22–32	16,993,623
East Coyote	plunging anticline	1120	2700–4000	14–25	97,873,916
West Coyote	domal	1030	2800–4450	14–30	
Huntington Beach	domal (?)	2750	2100–5200	14–29	75,890,778
Inglewood	domal	900+	1200–3100	20–25	8,953,900
Long Beach	domal	1160	2400–5900	23–31	174,770,453
Montebello	domal	1201	2100–4700	11–28	61,484,082
Richfield	domal	1104	2700–4500	16–27	33,366,697
Rosecrans	domal	378+	3800–7591	32–43	4,893,720
Sante Fe Springs	domal	1435	3500–4700	28–35	130,019,031
Seal Beach	domal (?)	discovery well	4620	25.3	15,000±
Beverly Hills	domal	84	2450–2700	12–16	60,035,466
Los Angeles City	monoclinal	110	500–1500	14–19	
Salt Lake	plunging anticline	900	1000–3100	11–22	
Brea-Olinda	monoclinal	1677	900–4450	15–32	107,504,132
Puente	domal				
Newport	monoclinal (?)	20±	800–1400	8–12	23,400±
Torrance	plunging anticline	4400	2700–3900	12–27	30,096,017
Whittier	monoclinal	605	600–3300	15–28	11,247,323
Total					813,167,538±

SUBSURFACE CRETACEOUS SECTION OF SOUTHWEST BEXAR COUNTY, TEXAS[1]

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The majority of wells drilled in the Luling fault zone of southwest Texas, paralleling the Balcones fault, stop after testing the top of the Edwards limestone, the oil-producing horizon sought by the prospector. In the Luling field, Caldwell and Guadalupe counties, the drill has perforated the entire section of Comanchean rocks to the basement schists; but in the vast faulted region lying southwest of Luling and extending to the Mexican border, there is available but scattered and meager knowledge of the lithology of the subsurface Comanchean sediments beneath the Edwards limestone or of the potentialities that they may possess of oil accumulation.

A deep test, drilled by A. L. Ballard and Rox Underwood, of San Antonio, for the Milham Corporation of Texas, and plugged and abandoned in February, 1926, at a total depth of 5,361 feet, furnishes an almost complete section of the Cretaceous, both Upper Cretaceous and Comanchean, in that part of the Luling fault zone lying in southwest Bexar County and adjacent areas. This hole, Milham Corporation of Texas, No. 1 Eastwood, is in the southwest portion of Bexar County, on the E. Eastwood 123-acre farm, on the northwest edge of the Somerset shallow oil field. The test is $1\frac{1}{2}$ miles southwest of the town of Somerset on the San Antonio and Southern Railway; about $\frac{1}{4}$ mile north of the Atascosa County line; 18 miles southwest of the city of San Antonio; and approximately 20 miles south of the main Balcones fault.

Due to lack of paleontological examination of shallow cuttings, and to absence of definitive lithologic markers in the driller's log, it is impossible accurately to delimit the formations above the Austin chalk, or to state with precision the thicknesses of these for-

[1] Published through courtesy of Milham Corporation, of Texas, San Antonio, Texas.

mations individually. The estimates here given of the thicknesses of the Wilcox, Midway, Navarro, and Taylor formations are thus more or less arbitrary and may contain a considerable percentage of error. The formations below the top of the Austin chalk may be distinguished satisfactorily.

The geologic section of No. 1 Eastwood (barometric elevation of derrick floor, 650 feet) follows:

EOCENE

Wilcox.—The reddish, sandy soil of the Indio, the basal series of the Wilcox, outcrops at the surface. To 364 feet, the log records sand and sandy shale, carrying pyrite. This sandy section, although it grades into the underlying shale series, is taken to represent the Wilcox.

Midway.—From the base of the foregoing sand section to the top of the Austin chalk, the log record is almost entirely "shale," "sticky shale," and "bowlders." The base of the Midway is taken arbitrarily by subtracting from the depth of the top of the Austin chalk the estimated thickness of the Navarro-Taylor beds, giving 667 feet as the bottom of the basal Eocene. This figure supplies an estimate of 303 feet as the thickness of the Midway, from 364 feet to 667 feet.

UPPER CRETACEOUS

Navarro-Taylor.—The thickness of the combined Navarro-Taylor is estimated as 900 feet, using the figures of Sellards[1] for Bexar County. The Navarro-Taylor column is thus estimated as extending from 667 feet to 1,567 feet. The section is almost entirely shale. Oil shows were encountered at 997 feet and at 1,310 feet.

Austin chalk.—From 1,567 feet to 2,010 feet are 443 feet of typical gray and white Austin chalk. From 1,647 feet to 1,654 feet, and at 1,690 feet, cores show the chalk stained a dark brown with oil. However, an offset to No. 1 Eastwood, Milham No. 2 Eastwood, sunk purposely to test this oil horizon, failed to give any promise of developing commercial production. The oil-soaked cores carry many impressions resembling small twigs and branches. Possibly

[1] E. H. Sellards, "The Geology and Mineral Resources of Bexar County," *Univ. of Texas Bull.* 1932, (1919), p. 20.

the saturation is due to a localized formation of petroleum by the decomposition of a mass of vegetable matter incorporated in the chalk. The occurrence of plant remains in limestone, although uncommon, is not unknown. The writer has seen nodules of pure coal imbedded in the Glenrose limestones of Bandera County, Texas.

Eagle Ford Shale.—From 2,010 feet to 2,053 feet, are 43 feet of black, bituminous shale representing the Eagle Ford.

COMANCHEAN

Buda Limestone.—Strata 101 feet thick, from 2,053 feet to 2,154 feet, logged as "lime" are presumed to represent the Buda limestone. An oil show occurred in limestone at 2,053 feet, at the contact of the Eagle Ford and Buda.

Del Rio Clay.—The Del Rio clay has a thickness of 78 feet, from 2,154 feet to 2,232 feet. It is a blue, rather fissile shale, carrying dwarfed specimens of *Exogyra arietina.*

Georgetown Limestone.—A small limestone section 46 feet thick, from 2,232 feet to 2,278 feet, above a large cavern or fissure, is correlated as "Georgetown."

Edwards Limestone.—From 2,278 feet to 3,002 feet are 724 feet of gray and white limestone, of varying hardness. The top of the Edwards is correlated as the cavern, mentioned in the preceding paragraph, a huge, subterranean cavity, in which drilling returns were lost, and into which it was necessary to pour tons of mud, cottonseed, and other packing. No oil was found in the Edwards, nor was sulphur water encountered.

Comanche Peak Limestone.—A section of "lime and shale," logged after over 700 feet of solid limestone, is taken to indicate the Comanche Peak. It is 75 feet thick, from 3,002 feet to 3,077 feet.

Walnut Clay.—Twenty feet of yellow clay, from 3,077 feet to 3,097 feet, is correlated as the "Walnut Clay."

Glenrose Limestone.—The Glenrose limestone is 1,785 feet thick, from 3,097 feet to 4,882 feet. Lithologically, it is variable. The upper 100 feet is yellow limestone. This is succeeded by about 300 feet of sediments logged only as "lime," then by another 100 feet of yellow lime, followed by 400 feet, more or less, of limestone, often blue in color and much harder than the yellow limes. Below

this, the limestone for about 50 feet is arenaceous. It then grades into black or blue-black limestone, in places quite sandy, in other places very shaley in appearance. This dark-colored section is approximately 100 feet thick and furnishes oil shows. Cores of bituminous nature, carrying a small amount of oil, were taken at 4,046, 4,056, 4,121, and 4,131 feet. Immediately below the black lime is a thin stratum of hard, white, pure crystalline limestone. The remainder of the section, approximately 750 feet thick, consists of lime, chiefly light yellowish or whitish in color.

Trinity Sand.—The well stops in basal Trinity conglomerate, and is believed to have revealed very nearly the entire thickness of the Trinity, as 479 feet of the formation, from 4,882 feet to 5,361 feet, is penetrated. The transition from Glenrose to Trinity is sharp. The thick Glenrose limestones are succeeded immediately by 65 feet of buff or yellow-red, hard, fine-grained sandstone with calcareous cement. Directly below the buff sandstone is a 3-foot layer of white quartzite, so indurated that 6 sets of rock cones and 72 hours of time were necessary to perforate it. A core at 4,950 shows a hard, impure, blue sand, with laminations of lignite, that have a 30° dip, but whether true dip or cross-bedding, it is impossible to say. About 400 feet of arenaceous deposists follow[1], ranging from sandstone to sandy shale, in some places blue in color, and having a few limy layers. The bottom of the section consists of grits and conglomerates, approximately 40 feet thick. Parts of this column are true grits, with a matrix of small, white or gray, angular to sub-angular quartz grains, in which are imbedded small, rounded quartz pebbles, and numerous, tiny, black chert (?) particles. Other parts of the section approximate fine conglomerates, having the same mass of quartz grains as a matrix but containing much larger quartz pebbles, oval or ellipsoidal and as much as 1 inch long and ½ inch in diameter. There are also small masses of white kaolin,

[1] There is some confusion at this depth and two different versions of this part of the well record exist. The record used by the writer gives the sandy section mentioned above. The other log notes about 140 feet of limestone beneath the buff sand taken to represent the top of the Trinity. Those who prefer to use this other version will, then, calculate the thickness of the Glenrose as 1,994 feet, from 3,097 feet to 5,091 feet, including in the basal Glenrose the buff sand column. Carrying forward this calculation will give 270 feet as the thickness of Trinity penetrated.

presumably formed by the alteration of feldspar, and, in some cases, seeming to preserve the cleavage faces of the original silicate. Cores contain no material of igneous or metamorphic nature—no granite, basalt, fresh feldspar, nor schist. The color of the grits and conglomerates is dominantly white and gray; and in the entire Trinity section the only place where the characteristic yellow and red coloration of the surface outcrop is found is the buff sandstone at the top of the formation. Neither oil nor water was found in the Trinity.

The total thickness of Cretaceous rocks revealed in cross-section by the well[1] is 4,694 feet: at least 1,386 feet of Upper Cretaceous (from 667 feet to 2,053 feet), and 3,308 feet of Comanchean (from 2,053 feet to 5,361 feet). Since the top of the Cretaceous cannot be differentiated accurately in the log, and since the well stops in the basal Trinity, it is likely that the complete Cretaceous section for southwest Bexar County may be considerably in excess of 4,694 feet, probably approximating 4,900 feet in thickness.

The section revealed by this well suggests several interesting geologic speculations:

1. WHAT ARE THE POSSIBILITIES OF OIL ACCUMULATION IN THE COMANCHEAN BENEATH THE EDWARDS LIMESTONE?

The black lime section of the Glenrose, around 4,050–4,150 feet, carried some oil; not much, to be sure, but the rocks undoubtedly had a bituminous odor and a small petroleum content. Under proper conditions of structure and porosity, it is the opinion of the author that this part of the Glenrose may perhaps serve as a reservoir of oil in commercial quantities. The Trinity sands showed no oil. However, there is always the possibility that the Trinity may carry petroleum, depending largely upon the nature of the underlying rocks, whether granite or schist, or Pennsylvanian limes and shales.

[1] Those who may wish to compare the Cretaceous section of southwest Bexar County with the section of the Luling field, are referred to E. W. Brucks, "The Luling Field, Caldwell and Guadalupe Counties, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 642–47.

2. DOES THE PENNSYLVANIAN UNDERLIE THE COMANCHEAN IN THIS REGION?

The well, stopping in basal Trinity, reveals no specific answer to this query. It is the opinion of the writer, however, that the pre-Cretaceous beds of southwest Bexar County are schists or unmetamorphosed igneous rocks, not sediments of Pennsylvanian age. A well in northwest Bexar County, drilled on Camp Bullis Reservation, immediately south of the Balcones escarpment, went directly from the Comanchean into dark, pre-Cambrian schists,[1] presumably the Packsaddle schists. It is not thought likely that Pennsylvanian beds will be found in southern Bexar County, for such deposits would require the postulation of a wedge or salient of Pennsylvanian jutting into the county from the west, and a considerable distance south of the Balcones escarpment—an improbable happening.

3. SHOULD PENNSYLVANIAN OIL-BEARING SEDIMENTS EXIST, WHAT ARE THE PROSPECTS OF PROFITABLE ECONOMIC EXPLOITATION?

In view of the great thickness of Comanchean revealed in the well, Pennsylvanian sediments, if present, will be found only at great depths, from 5,400 to 5,600 feet probably, in southwest Bexar County and areas similarly situated. This is too deep for profitable exploitation in the present status of well-drilling technique, unless large production is assured. Few companies can afford to sink holes over a mile deep solely on a hypothetical chance of finding Pennsylvanian rocks.

4. WHAT IS THE SIGNIFICANCE OF THE BLACK LIME SECTION OF THE GLENROSE IN RELATION TO ALLEGED PENNSYLVANIAN ROCKS REPORTED ENCOUNTERED BY THE DRILL IN VARIOUS PARTS OF SOUTHWEST TEXAS?

In various wells in different counties of southwest Texas, bordering the Balcones fault on the south, rocks alleged to be Pennsylvanian in age have been reported from time to time. These reports

[1] J. A. Udden, "The Geology and Mineral Resources of Bexar County," *Univ. of Texas Bull.* 1932 (1919), pp. 131, 132.

have given rise to a widespread idea that there is an extensive deployment of Pennsylvanian deposits beneath the Comanchean strata. In nearly all of these alleged cases, determination of the samples as Pennsylvanian has been based upon the black color and bituminous nature of the cuttings.

Much illuminating information on this important subject is furnished by the Eastwood well. The black lime section at 4,050–4,150 feet, carrying a small amount of oil, is almost identical lithologically with the Bend lime of north-central Texas. The author compared cores of this black lime, under the hand-lens, with various samples of Bend lime from producing wells in Stephens, Eastland, and other counties of the Ranger district, and could make no distinction. Samples of the dark, Glenrose lime examined by company technologists were stated to resemble lithologically the Marble Falls limestone more than any other known formation, having the same color, a bituminous nature, and carrying possible sponge spicules. Yet the dark lime in the Eastwood well is without doubt Glenrose in age, as shown both by the stratigraphic section and by fossils found in it, particularly, impressions closely resembling *Orbitulina texana*, a diagnostic Glenrose type.

Thus, there exists in southwest Texas a horizon in the Glenrose that can scarcely be distinguished from the Marble Falls limestone of the Bend series of the Pennsylvanian. This remarkable coincidence renders the correlation of rocks encountered by the drill in southwest Texas as Pennsylvanian on the basis of lithology, a hazardous proceeding. In the judgment of the author, no black limes or shales beneath the Edwards limestone in southwest Texas should be called Pennsylvanian in age, unless Pennsylvanian fossils are found, or unless the Trinity sands have previously been drilled through.

April, 1926

AN INTERESTING EXAMPLE OF A SURVEY OF A DEEP BORE HOLE

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ABSTRACT

A survey of the course of a well, by the Anderson method, yielded interesting data on deflection of bore holes drilled by rotary tools. The two most important factors causing deflection in this well appear to have been changes in lithology and the whipstock action of sidetracked drill-pipe. All of the deflections thought to have been caused by changes in lithology are in a clockwise direction, while most of the deflections ascribed to mechanical difficulties are in a counter-clockwise direction. The latter relationship is thought to be entirely accidental, but it is believed that the first relationship cannot be fortuitous. A further conclusion is that no reliance can be placed on the dips observed in cores without a knowledge of the angles of inclination of the hole at the points where the cores were taken.

INTRODUCTION

The McFarland No. 1 well of Oak Ridge Oil Company, at which the survey here described was made, is located in the western portion of Los Posas Rancho, Ventura County, California, about 3 miles west of Somis, roughly, 50 miles west of Los Angeles and 15 miles east of Ventura. The well was drilled to a depth of 6,066 feet, through sedimentary rocks of Fernando (Pliocene) age and sedimentary and volcanic rocks of Monterey (Miocene) age. When the hole had been carried to a depth of 5,295 feet, a survey was undertaken to ascertain its deflection from vertical and to obtain data to aid in determining the dip of the formation at the bottom of the hole. The survey was made by Mr. Alexander Anderson.

GEOLOGY OF THE BORE HOLE

The well is located on the crest of a dome in which sands, clays, and shell reefs of the Saugus formation (Upper Fernando) of Upper Pliocene age are the oldest rocks exposed at the surface.

Fernando beds were found to extend to a depth of 1,343 feet, of which the upper 389 feet are soft sands and yellow clays, and the lower 954 feet are hard pebbly sands and blue clay shale.

At 1,343 feet a very decided change in lithology occurs where the sands and clay shales of the Upper Fernando are underlain by thinly laminated, light- and dark-banded, calcareous brown shale or marl with occasional very thin layers or crusts of white limestone. The shale is sufficiently calcareous to be called marl. At about 1,440 feet the shales become less calcareous and more siliceous. Thin layers of impure diatomaceous earth appear. A sample taken at 1,450 to 1,456 feet contains a few thin layers of bluish-gray tuff, interbedded with brown marl and impure diatomaceous earth. Below 1,456 feet the bore hole continues through hard, brown, calcareous shales and soft, brown siliceous organic shales to a depth of 1,787 feet. The change from sands and blue clay shale to brown marls and diatomaceous shales, which occurs at 1,343 feet, constitutes such a marked change in lithology that there can be little doubt that the brown marl represents the youngest member of the Monterey series at this locality.

At 1,787 feet the bit entered dense, fine-grained, light-gray-to-cream-colored limestone.

Below 1,855 feet an increase was noted in the quantity of accessory mineral fragments included in the limestone, which are believed to represent volcanic tuff. At 1,900 feet the bit entered basalt. From 1,900 feet to 1,962 feet the bore hole penetrates massive, fine-grained, dark blue-gray basalt. From 1,962 to 2,467 feet the drill penetrated alternating beds of basalt, dacite, tuff, tuffaceous brown shale, brown shale, and gray sand.

From 2,467 to 2,497 a second thick layer of massive basalt was penetrated. Below this sheet to 5,074 feet the hole passed through alternating layers of volcanic agglomerate, brown shale, and gray sand. The shales vary considerably in their nature, but taken as a whole are similar to the shales of the Monterey series found in other localities. Certain of the shale layers break into small angular fragments, apparently under the influence of the drilling fluid, and slough into the hole in such quantity as seriously to impede drilling. Several of the fishing jobs resulted from the burial of the tools by such "running shale."

Below 5,074 feet, to the bottom of the hole at 6,066 feet, alternating layers of brown shale and gray sand were encountered.

Numerous core samples were taken during the drilling of the well, but, due to the nature of much of the material penetrated, most of the cores yielded no trustworthy information on the attitude of the beds. Cores taken in the interval from 4,800 feet to 6,066 feet show apparent dips varying from horizontal to 25°. An oriented core, taken at 5,295 feet, shows an apparent dip of 9°, but a true attitude ap-

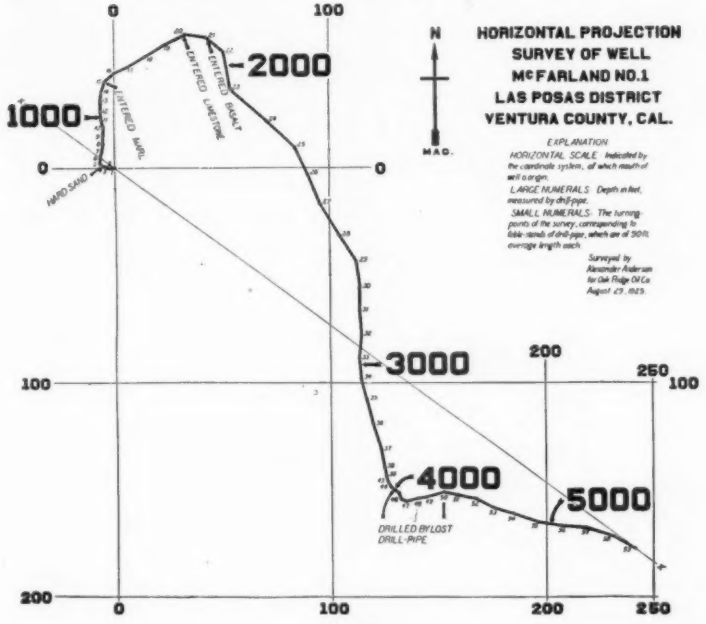
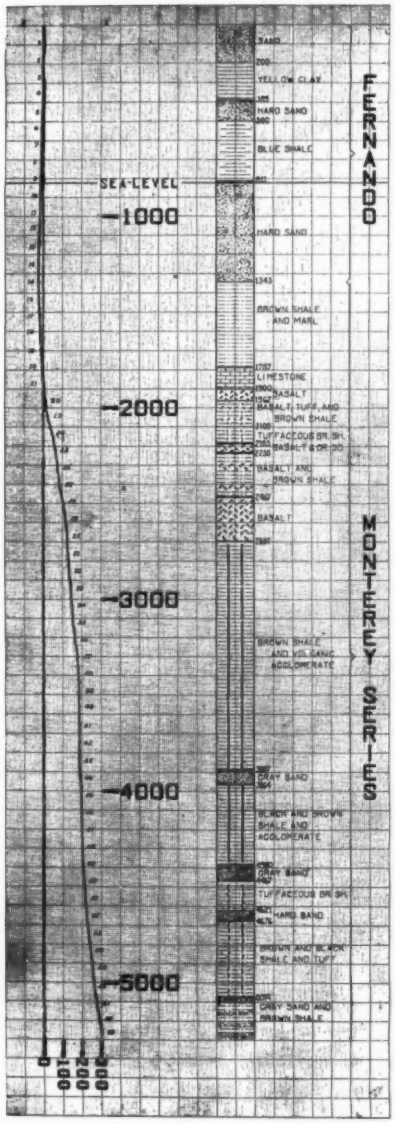


FIG. 1

proximating horizontal. It is believed that the beds penetrated by this hole have, in general, dips of less than 10°, and that the dip nowhere exceeds 20°.

SURVEY OF THE BORE HOLE

A survey of the well was made by Mr. Alexander Anderson, whose method consists in lowering a self-recording instrument into the hole on the end of the drill pipe and taking a reading after each stand of drill pipe has been screwed on and lowered to the derrick floor. The



"foble-stands" of pipe averaged 90 feet in length, so that his results gave the deflection from vertical and the azimuth of the deflection at stations located at intervals of 90 feet. The results of the survey are indicated on the accompanying chart (Fig. 1) representing the horizontal projection of the course of the bore hole, and on the accompanying vertical section (Fig. 2) representing the projection of the course of the well on a vertical plane passing through the mouth of the well and the bottom of the well at the time the survey was made, that is, at 5,295 feet depth.

By referring to Figure 1, noteworthy changes in the azimuth of the bore hole will be seen at eight points, namely, at stations 5, 15, 20, 21, 22, 23, 29, and 46, and one additional point at which a change in vertical deflection occurs in connection with a moderate change in azimuth, namely at sta-

FIG. 2.—Projection of the course of the McFarland No. 1 bore hole on a vertical plane passing through the mouth of the well and its bottom when at 5,292 feet.

tion 39. In the following tabulation (Table I) the survey data have been summarized, using the foregoing points of noteworthy deviation as the turning-points of the summarized survey, and eliminating the intervening stations:

TABLE I

Stations		Depth in Feet Measured by Drill Pipe		Average Deflection from Vertical	Average Azimuth of Bore Hole (Magnetic)
From	To	From	To		
0	5	0	449	0°56′	N.74°W.
5	15	449	1,342	2°28′	N. 4°E.
15	20	1,342	1,792	5°37′	N.61°E.
20	21	1,792	1,882	6°00′	S.81°E.
21	22	1,882	1,972	6°50′	S.50°E.
22	23	1,972	2,062	11°00′	S.11°E.
23	29	2,062	2,605	10°34′	S.36°E.
29	39	2,605	3,506	6°24′	S. 8°E.
39	46	3,506	4,136	1°22′	S.36°E.
46	59	4,136	5,295	5°43′	S.78°E.

HISTORY OF DRILLING

The following tabulation (Table II) presents the outstanding mechanical features of the hole.

TABLE II

Depth (Feet)		Diameter of Hole (Inches)	Type of Bit Used	Casing	
				Depth (Feet)	Diameter (Inches)
0	1,318	20	Fishtail	.....	.....
1,318	1,791	17 1/4	Fishtail	.....	.....
1,791	2,713	17 1/4	Rock bit	.....	.....
2,713	3,670	17 1/4	Fishtail	3,672	11
3,670	4,268	14 1/2	Fishtail	4,147	8¼
4,268	4,490	10 1/2	Mostly fishtail	.....	.....
4,490	4,600	7 5/8	Fishtail	.....	.....
4,600	4,650	7 5/8	Rock bit	.....	.....
4,650	5,010	7 5/8	Fishtail	4,811	6¼
5,010	5,046	5 5/8	Fishtail	.....	.....
5,046	6,066	5 5/8	Rock bit*	.....	.....

* The rock bit was used here, not because progress could not be made with fishtail, but on account of somewhat more rapid progress possible with rock bit.

During the drilling through rapidly alternating hard and soft formations the drill pipe was "twisted off" many times, due to the

lack of delicate control on the electric drive. It was generally possible to "screw on" and recover the pipe without much delay, but on several occasions protracted fishing jobs resulted. It is believed that only those fishing jobs involving "drilling by" or "sidetracking" of pipe or tools could have caused deflection of the hole from its course pursued above the point of "sidetracking." A list of such fishing jobs is therefore presented:

1. While drilling at 3,551 feet, twisted off at 3,487 feet. Drilled by drill-stand 3,487 to 3,551 feet and recovered lost stand with wall hook on overshot.
2. While drilling at 4,489 feet, twisted off at 3,996 feet. Drilled by lost pipe to 4,268 feet, placed cement plug to 4,079 feet, drilled by lost pipe to 4,489 feet, and landed $8\frac{1}{4}$-inch casing at 4,147 feet.
3. While drilling at 5,010 feet, twisted off at 4,370. Drilled by to 4,470 feet. Lost 107 feet of the sidetracking string and rock bit. Drilled by pipe and rock bit 4,363 to 4,410 feet. Placed cement plug to 4,130 feet. Drilled by lost pipe to 4,812. Landed $6\frac{1}{4}$-inch casing at 4,811 feet. Sidetracked lost pipe 4,811 to 5,010 feet.

DEFLECTION OF BORE HOLE INDUCED BY MECHANICAL DIFFICULTIES INCIDENT TO DRILLING

It is possible that changing the diameter of hole had an influence in deflecting the hole at certain points. A decided change in azimuth occurs at station 15, at a depth of 1,342 feet, or 24 feet below the depth at which the hole was reduced from 20 inches to $17\frac{1}{4}$ inches in diameter. Inasmuch as the survey stations are at intervals of 90 feet, the difference of 24 feet is negligible, and the close correspondence might lead one to infer that the deflection of the hole was induced by change in size of bit. The deflection at 1,342 feet, however, may be due to the fact that the bit passed out of hard sand of the Fernando formation and entered soft marl of Monterey age at a depth of 1,343 feet.

At a depth of 4,490 feet the diameter of the hole was reduced from $10\frac{1}{2}$ to $7\frac{5}{8}$ inches, and it is interesting to note that the hole is deflected 28 degrees of azimuth to the right at station 50, at 4,500 feet depth.

It should be noted, however, that 4,489 feet marked the bottom of an important sidetracking job, which may have been the cause of the deflection.

Of the five points at which the hole was reduced in diameter, only two have any correspondence in depth with stations of the survey at which marked deflections occur, and in these two cases the deflection may have been caused by other agencies than a decrease in the size of the bit. It is therefore concluded that reduction of diameter is not a factor in causing deflection of hole.

Change in type of bit may conceivably have had an influence in causing deviation in the course of the hole. However, as rock bits were generally used as soon as the hole entered hard formation, being replaced by fishtail bits as soon as the hard layer was penetrated, it is impossible to distinguish, in most cases, between deflections caused by changes in type of bit and those caused by lithologic changes. Furthermore, at the only point in the hole where the type of bit was changed without a marked change in lithology, namely, at 5,046 feet depth, the hole pursued an exceptionally straight course. It seems reasonable to conclude that changes in type of bit had no appreciable effects on the course of the hole.

No conclusions are possible as to the effect of reducing the size of casing through which drilling was conducted, inasmuch as drilling was always carried past the landing point of the various strings of casing prior to the introduction of the casing.

One type of mechanical difficulty, however, had an unmistakable influence on the course of the bore hole, namely, the presence of lost pipe in the hole. At station 39 the inclination of the hole from vertical changed from an average of 6° 24′ to 1° 22′, the average azimuth of the hole being deflected at the same time from S. 8° E. to S.36° E., that is 28° to the left. Station 39 is at 3,506 feet depth, and it is believed that the sidetracking of a stand of drill pipe between 3,487 and 3,551 feet was responsible for this deflection of the hole.

At station 46 the hole is deflected from an azimuth of S. 36° E. to S. 78° E., or 42° to the left, the angle of deviation from the vertical changing from an average of 1° 22′ to 5° 43′. Station 46 is at 4,136 feet depth, and this point in the hole is within the intervals of depth of two sidetracking jobs.

It is noteworthy that the two changes of course of the bore hole which appear to be certainly the result of the "whipstock" action of

lost drill pipe involve counter-clockwise turns in azimuth. With one exception, all of the other noteworthy deflections of the hole are clockwise turns in azimuth.

INFLUENCE OF LITHOLOGIC CHANGES ON DEFLECTION OF BORE HOLE

The well offers exceptional opportunities for observing the deflection of a bore hole caused by lithologic changes, as the formations penetrated varied greatly in hardness, in induration, and in their ability to stand without sloughing into the hole.

From the accompanying illustrations showing the changes in azimuth and inclination of the hole, it can be seen that those changes not directly traceable to mechanical difficulties, such as side-tracking, are usually caused by changes in lithology. The rotation of the bit is clockwise, and it is of interest to note that four important changes in lithology of the rocks drilled through are accompanied by noteworthy deflections in azimuth of the hole in a clockwise direction.

The first marked change in azimuth takes place at station 4, at a depth of 358 feet, where the azimuth changed $25\frac{1}{2}°$. At station 5, depth 448 feet, the change is even greater, being 53°. Both changes are in a clockwise direction. Above this the maximum inclination of the hole from the vertical is 1°, while below station 5 the inclination increases to over 2°. At a depth of 389 feet the bit passed from soft yellow clay into hard sand and continued in the latter to a depth of 500 feet. This lithologic change corresponds closely to the change in azimuth, as the top of the hard sand, 389 feet, lies between stations 4 and 5. It is believed that a closer correspondence is not to be expected, inasmuch as the stations are 90 feet apart and, further, as the survey was made after casing had been introduced into the hole. In this part of the bore, 11-inch casing had been run into a $17\frac{1}{2}$-inch hole, and therefore the exact point of change would not necessarily stand out. From the survey it appears that the change in azimuth caused by the hard sand is 78° in a clockwise direction and the change in inclination from the vertical is over 1°.

A decided change in azimuth takes place at station 15, at a depth of $1{,}342\frac{1}{2}$ feet, which agrees almost exactly with the top of

the brown shale and marl logged at 1,343 feet. In this case the change is from hard sand to relatively soft shale and marl. The average change in azimuth is 57° in a clockwise direction, and this is accompanied by a change in inclination from the vertical. The average inclination of the bore in the hard sand above the marl is 2° 28′, while the average inclination in the shale and marl is 5° 37′.

At a depth of 1,787 feet hard limestone was encountered below the shale and marl, and a corresponding clockwise change in azimuth of approximately 38° takes place at station 20, depth 1,792 feet. It is accompanied by only a relatively small change in inclination from the vertical.

A lesser change occurred where basalt was encountered at approximately 1,900 feet. At station 21, depth 1,882 feet, there is a clockwise change in azimuth of 31° and an increase in inclination from the vertical of about 1°. A rock bit was used in drilling through both the hard limestone and the basalt.

The very decided clockwise change in azimuth which takes place between stations 20 and 22 appears to be due to the influence of the hard limestone and basalt. The total change in azimuth from the top of the limestone (station 20) to station 22, which is in basalt, is 107°. At station 20, depth 1,792 feet, the inclination from the vertical is 7° 15′; this increases to a maximum of 14° 18′ at station 24, depth 2,153 feet.

At station 23, at a depth of 2,062 feet in basalt and brown shale, there is a counter-clockwise change in azimuth of 25°. It is the only counter-clockwise change in azimuth that cannot be traced directly to some mechanical difficulty, such as the sidetracking of drill pipe. No important change in lithology occurs at this point and it cannot, therefore, be explained as due to either a mechanical difficulty or to a lithologic change. During the drilling, below the first layer of basalt, it was not uncommon for pieces of basalt, sometimes of considerable size, to break from the wall, due to the whipping action of the drill pipe, and to fall into the hole. It is possible that the counter-clockwise change in azimuth at station 23 may be due to such a piece of basalt which acted as a wedge or whipstock and so caused the deflection of the hole.

At station 29, depth 2,604 feet, there is a 27° clockwise change in

azimuth and a decrease in inclination from the vertical of several degrees. This does not correspond exactly with a change in lithology, but takes place in a thick sill of basalt which extends from 2,467 to 2,697 feet.

At station 57, depth 5,103 feet, a slight clockwise change in azimuth, about 10°, may be due to the fact that at 5,074 feet the bit passed from shale into sand. However, such small changes in azimuth may be due to causes other than lithologic change.

From a comparison of the survey with the log of the well it is at once apparent that all of the important changes in azimuth, except those directly traceable to mechanical difficulties incident to drilling, correspond closely with marked changes in lithology, and that these changes are all clockwise.

This clockwise change in azimuth appears to occur at the more important points of lithologic change, whether the change be from soft beds into hard, or vice versa. In several other well surveys casually examined by the writer, the common changes in azimuth are clockwise. In this connection it is worthy of note that the rotation of the bit is also clockwise. Although relatively few surveys have been examined by the writers, the clockwise migration of the hole appears to take place too often to be purely fortuitous.

CONCLUSIONS

A detailed study of the survey of the McFarland well No. 1, together with casual examination of surveys of two other wells, has led to certain conclusions:

1. The two most important factors in causing deflection of bore holes are lithologic changes and the whipstock action of sidetracked drill pipe.

2. All of the deflections which appear to have been induced by changes in lithology are in a clockwise direction. It is thought that this relationship is not fortuitous, but will prove to hold true for wells drilled in flat or gently dipping beds.

3. The majority of the observed deflections which appear to have been caused by mechanical difficulties incident to drilling are counter-clockwise. The writers can see no fundamental reason why this should be the case, and they believe that, if a sufficiently large

number of surveys were studied, the deflections caused by mechanical difficulties would be found to be equally divided into clockwise and counter-clockwise turns.

4. Inasmuch as the maximum inclination of the hole from vertical, as indicated by survey, is frequently comparable in amount to the dips as measured in the cores, it would seem that no reliance can be placed on the apparent dips observed in cores without knowledge of the inclination of the hole from vertical at the points where the cores were taken.

5. In a group of wells drilled within no great distance of one another, it is believed to be possible, without taking oriented cores, to determine the true direction and amount of dip by correlating the survey data with the dips measured in core samples.

THE SUBDIVISION OF THE ENID FORMATION

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ABSTRACT

As the result of the work of a number of geologists in northern Oklahoma during the past few years, the Enid formation which, as originally generally described, included the Permian red beds of Oklahoma below the Blaine gypsum, is subdivided into six formations, named in ascending order, the Stillwater, Wellington, Garber, Hennessey, Duncan, and Chickasha.

This paper, written as the result of a field conference in this region in March, 1926, describes these various formations and discusses their correlation.

INTRODUCTION

As originally described, "the Enid formation includes all the rocks of the red-beds formation from the base of the Permian to the lowermost of the gypsum ledges on the eastern slope of the Gypsum Hills."[1] This included the Harper, Salt Plain, Cedar Hills, and the greater part of the Flowerpot shales of Cragin's original description of the formations of the Cimarron group.[2] From this description it will be understood that the Enid formation as originally described included only Permian red beds, and was not intended to include the non-red Permian of north-central Oklahoma, which beds include, in descending order, the Sumner group, composed of the Wellington and Marion formations, and the Chase and Council Grove groups of the various Kansas authors.[3]

It should also be understood that at the time the Enid was first

[1] Charles N. Gould, "Geology and Water Supply of Oklahoma," *U. S. Geol. Survey Water Supply Paper No. 148* (1905), p. 39.

[2] F. W. Cragin, "The Permian System of Kansas," *Colo. College Studies*, Vol. 6 (1896), pp. 18–26.

[3] See especially Charles S. Prosser, "Revised Classification of the Upper Paleozoic Formations of Kansas," *Jour. Geol.*, Vol. 10 (1902), pp. 703–37.

described it was believed that the line of separation between the Pennsylvanian and Permian should be drawn at the base of the Wreford limestone.[1] The southern extension of the Wreford into Oklahoma had not then been mapped, but it was assumed to pass southwestward near the towns of Stillwater, Coyle, and Oklahoma City, reaching south Canadian River, then the southern boundary of Oklahoma territory, a few miles west of Norman. This fact is shown on the map (Plate 1) accompanying *Water Supply Paper 148.*

If, however, we accept the base of the Cottonwood limestone as the base of the Permian, as is now done by the United States Geological Survey and the Kansas Geological Survey,[2] and at the same time consider that the base of the Enid is the line of Pennsylvanian-Permian contact as was originally intended, it will be necessary to shift the base of the Enid a number of miles east of the line originally drawn. At the time of this writing the Cottonwood limestone has been definitely traced only as far south as a point about six miles south of Pawnee; but the Cushing limestone, which lies not far below the Cottonwood stratigraphically, and is a much more persistent ledge, has been carried to a point on north Canadian River southwest of Prague. By following associated sandstone beds it is possible to carry the approximate base of the Pennsylvanian-Permian contact, otherwise the base of the Enid red beds, south across eastern Pottawatomie County to connect with the Konowa formation, which is considered by Morgan to be the base of the Permian.[3] This line as tentatively drawn is shown on the map (Fig. 1).

It is a well-known fact, which need not here be discussed in detail but simply reiterated, that the line of color change in the Permian rocks of north-central Oklahoma and southern Kansas does not fol-

[1] *Op. cit.*, p. 31, also p. 34.

[2] The authors do not at this time wish to express an opinion as to the exact location of the Pennsylvanian-Permian contact. During the past twenty years the line has been shifted up and down the geologic scale through a distance of several hundred feet. Beede, our best authority on the Permian, places the line at the Neva or the Elmdale. Other geologists would place it as high as the Herington. Although the U. S. Geological Survey now places this boundary at the base of the Cottonwood limestone, it is with the understanding that the boundary between Pennsylvanian and Permian is subject to change whenever there is general agreement that another line is more nearly in accord with the accepted boundary in other parts of the world.

[3] George D. Morgan, "Geology of the Stonewall Quadrangle," *Bureau of Geology, Bull. No.* 2 (1924), p. 140, 141.

low the strike of the beds, but transgresses this strike at an acute angle, cutting diagonally successively lower formations, including,

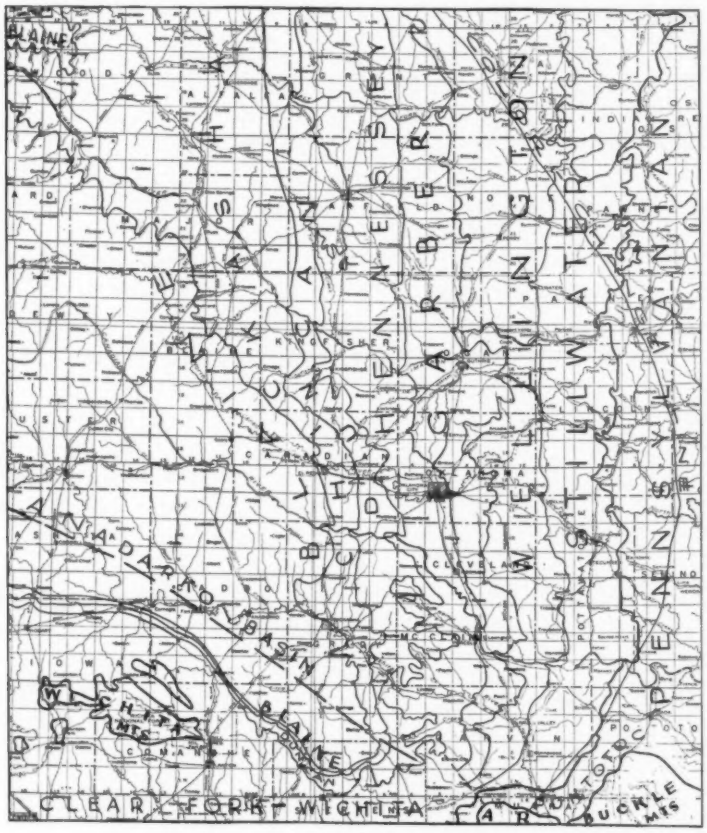

FIG. 1.—Map of part of north-central Oklahoma showing the formation included in the Enid group.

from above downward, the Wellington, Pearl, Herington, Enterprise, Luta, Winfield, Doyle, Fort Riley, Florence, Matfield, Wreford, Garrison, Cottonwood, and lower beds. This fact must always be kept in mind in considering the Permian rocks of the region.

RECENT INVESTIGATIONS OF THE ENID

With these elemental facts in mind let us turn to the immediate study of the problem at hand, namely, the subdivision of the Enid formation.

Work accomplished in north-central Oklahoma during the past decade by a number of geologists, especially that done during the past five years by geologists in the employ of various oil companies, has added much to our information regarding the Enid formation, both surface and subsurface. Many pertinent facts, previously unsuspected, have been discovered, and in the light of more complete data it has become necessary to revise many of our former ideas.

As these studies have progressed two major facts have become increasingly evident. First, it is not feasible in this region to separate the Permian along the color-change line, but, on the other hand, the various non-red formations as first described in Kansas can and must be carried southward until they merge with the typical red beds of the Enid. Second, the red beds of the Enid formation can be divided into mapable units. It naturally follows that in order that these units may be manipulated it is necessary to assign to them certain definite names.

The work of various geologists working more or less independently through a series of years has been crystallized as a result of a series of field conferences, which have been held during the past few months under the direction of the Oklahoma Geological Survey. These conferences have been participated in by more than a hundred working geologists of Oklahoma, Kansas, and Texas. Three of these field conferences have dealt, in part at least, with the various problems of the Enid.

As the result of the first conference held in 1924, at which time the presence of the Anadarko Basin, in southwestern Oklahoma, was definitely determined and mapped, two formations, the Chickasha and the Duncan, were segregated from the upper part of the Enid.[1] At that time, however, the lower part of the Enid remained untouched.

[1] Charles N. Gould, "A New Classification of the Permian Red-Beds of Southwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8 (1924), pp. 322–41.

The fifth field conference, held on March 8, 9, and 10, 1926, in northern and central Oklahoma, participated in by the authors of this paper and by several other geologists who during the past few years have been working on the Enid formation, has brought together the ideas of the various men on the matter of subdivision and nomenclature of the Middle and Lower Enid, and it is particularly to this phase of the subject that this paper is addressed.

The major facts agreed upon as a result of the fifth field conference are as follows:

1. The Harper sandstones, first described by Cragin in southern Kansas, may be traced southward from the type locality in Harper County, Kansas, across north-central Oklahoma. The middle and upper parts of Cragin's Harper sandstones constitute a persistent sandstone bed which has been traced as far south as the vicinity of Blanchard, McClain County, where it is found to be the same as the Duncan sandstone of the Anadarko region of southwestern Oklahoma,[1] which in turn is believed to be the practical equivalent of the San Angelo formation of Texas.

2. Lying below this persistent sandstone bed occurs a series of shales, approximately 400 feet in thickness, representing part of the Lower Harper of Cragin, to which the new name "Hennessey shale" has been applied by geologists working in that region.

3. Below the Hennessey shale is a series of some 600 feet of red shales and massive sandstones, representing the basal Harper of Cragin, that have become known to the local geologists as the Garber sandstone.

4. Underneath the Garber is exposed a formation which in southern Kansas and northern Oklahoma has long been known as the "Wellington shale." In its type locality the Wellington consists of a drab or gray shale with numerous thin beds of gray "mud-stone," scattered impure limestones, and clay conglomerates. Southward the Wellington changes its characteristics; the shale first becomes red, and then sandstones begin to come in. From the Cimarron River southward the Wellington facies has entirely changed from

[1] Charles N. Gould, "Correlation of the Permian of Kansas, Oklahoma and Northern Texas," *ibid.*, Vol. 10 (1926), p. 152.

that of the type locality, and the formation consists of alternating beds of red clay-shale and red sandstone.

5. Between the base of the Wellington and the Pennsylvanian-Permian contact there is a series of Permian rocks up to the present

TABLE I

Units Recognized in Kansas	Names Proposed in This Paper	
Flowerpot shale Cedar Hills sandstone Salt Plain measures	Chickasha formation	
Harper sandstone: Upper Harper Middle Harper	Duncan sandstone	
Lower Harper	Hennessey shale: Bison banded member Fairmont shale member	
	Garber sandstone: Hayward sandstone member Lucien shale member	
Wellington shale		Enid Group
Marion formation: Pearl shale member	Wellington formation and Pearl shale member of Marion formation mapped together	
Herington limestone member Enterprise shale member Luta limestone member Chase group: Winfield limestone Doyle shale Fort Riley limestone Florence flint Matfield shale Wreford limestone Council Grove group: Garrison shale Cottonwood limestone	Stillwater formation	

time has received no definite name in Oklahoma. These beds probably include the equivalent of the Asher, Konowa, and Stratford formations of Morgan, as described in the Stonewall quadrangle in south-central Oklahoma, also the beds from the top of the Herington limestone to the base of the Cottonwood limestone of southern Kansas.

There are still several minor points, such as definite lines of contact and matters of subdivision of formations and assignment of certain beds, upon which the authors are not yet in full agreement. However, they all recognize that these points of difference are largely matters of the personal equation and interpretation, and are not necessarily vital to the main question. In this paper, then, the points upon which practical agreements have been reached will be presented.

The authors all agree that the term "Enid" as a formation name must fall. It is therefore proposed to retain the name as a group name, and to assign formation rank to the six major subdivisions of the Enid. In Table I an attempt is made to show the approximate equivalence of the various beds.

The accompanying map (Fig. 1) shows the surface outcrops of the greater part of the Enid group and of the six formations which constitute this group in Oklahoma. There is also shown on this map the approximate location of the color-change line in northern Oklahoma, which line should be kept in mind.

NEW CLASSIFICATION OF THE ENID

The description of the various formations of the Enid group, beginning with the oldest, is given in the following paragraphs:

STILLWATER FORMATION

This name is here proposed to include a series of red and gray sandstones and red shales exposed in a zone extending north and south across east-central Oklahoma. Its base is the base of the Cottonwood limestone and the southern equivalent of the same. The top of the formation is the top of the Herington limestone and its southern equivalent. Throughout a considerable part of the area of the outcrop of the Stillwater in central Oklahoma the exact location of neither the base nor the top of the formation has been accurately mapped at this time.

The equivalents of the Stillwater in southern Kansas and in Osage and Kay counties, Oklahoma, consist of a series of limestones and shales which constitute the Flint Hills named, in ascending order, as follows: Cottonwood limestone and Garrison shale of the Council Grove group, the Wreford limestone, Matfield shale, Florence flint, Fort Riley limestone, Doyle shale, and Winfield limestone of the Chase group, and the Luta limestone, Enterprise shale, and

Herington limestone members of the Marion formation of the Sumner group.

As one passes south these various beds begin to lose their identity in the region of the Arkansas River in southern Osage, northeastern Noble, and Pawnee counties. By the time the color-change line has been reached the limestones are thinning rapidly and are being replaced by sandstones, while the shales begin to change their color from gray to red. Still farther south the limestones disappear and the entire formation is found to consist of alternating beds of red shales and red and gray sandstones. This is typical Stillwater, as exposed at the type locality, Stillwater, the county seat of Payne County.

The southern equivalents of part of the Stillwater are probably to be found in Morgan's Stratford, Konowa, and Asher formations in the Stonewall quadrangle.[1]

The combined thickness of the various formations from the Cottonwood to the Herington, inclusive, as exposed on the surface in southern Kansas and northern Oklahoma approximates 540 feet.[2] In general, these beds are believed to thicken to the south. A fair estimate for the thickness of the Stillwater in east-central Oklahoma would probably be about 800 feet.

WELLINGTON FORMATION

The Wellington formation, first described by Cragin[3] in 1896, consists of gray to bluish and drab shales with numerous thin beds of gray "mud-stone." These same general conditions also obtain in a considerable part of Kay County, Oklahoma. At the color-change line, however, beds of red sandstone appear, and the color of the shales changes from gray and drab to red. The characteristic "mud-stones" persist, however, to the latitude of Perry, and the Wellington type of topography is still found as far south as Mulhall. South of Cimarron River practically all the original Wellington characteristics have been lost, and in eastern Logan, Oklahoma, and Cleveland counties, the Wellington is made up of alternating beds of red shales and red sandstones.

[1] George D. Morgan, "Geology of the Stonewall Quadrangle, Oklahoma," *Bureau of Geology, Bull. No. 2* (1924), pp. 140–42.

[2] Charles N. Gould, "Index to the Stratigraphy of Oklahoma," *Okla. Geol. Survey, Bull. 35* (1924), pp. 80–85.

[3] *Op. cit.*, p. 16.

The Wellington formation in Kansas rests on the Pearl shale member of the Marion formation, but since the Pearl shale member cannot be readily differentiated from the Wellington in Oklahoma it is mapped with the Wellington and, for purposes of mapping, the boundary is placed at the top of the easily recognized Herington limestone. The top of the Wellington is the base of the lowest heavy sandstone of the Garber formation. In some localities this contact has not yet been definitely established.

The thickness of the Wellington in northern Oklahoma is approximately 600 feet, and of the Pearl shale 70 feet.

GARBER SANDSTONES

The name Garber, which for several years has been employed by local geologists in the region under discussion, is here proposed to include a series of red clay shales, red sandy shales, and red sandstones lying above the Wellington. The name is from the town of Garber, in eastern Garfield County, Oklahoma, where the formation is well exposed and near which is located one of the larger oil fields of the state.

Geologists working in the field have learned to distinguish in a general way a lower shaly phase and an upper sandy phase of the Garber formation, and these phases are sometimes spoken of as the "lower Garber" and "upper Garber." In order to avoid the use of the terms "lower" and "upper" it has been thought best to consider these two phases of the Garber as members, and the following classification is therefore proposed.

Lucien shale member.—The lower part of the Garber sandstone as exposed throughout a considerable part of eastern Garfield, western Noble, and western Logan counties is composed largely of red, more or less fissile or laminated clay shales with several ledges of red sandstone. One of these ledges generally occurs at the base of the Lucien member, otherwise the base of the Garber sandstone. Other beds of red sandstone, more or less lenticular in nature, occur at higher levels, but the Lucien member as a whole is made up chiefly of red shales which are generally easily distinguishable from the blocky, red clay-shales of the younger Hennessey formation.

The thickness of the Lucien member approximates 250 feet. The

type locality for the member is the village of Lucien, in western Noble County, where the beds are well exposed.

Hayward sandstone member.—For the upper part of the Garber sandstone the name "Hayward sandstone member" is here proposed, the name being that of a village in southeastern Garfield County at which the Hayward beds are well exposed.

The Hayward member consists for the most part of heavy ledges of massive red sandstone, more or less lenticular, generally cross-bedded and not uncommonly conglomeratic, interstratified with beds of fissile shale and sandy shale. The sandstones, in many places, weather into conspicuous cliffs. The thickness of the member approximates 350 feet.

At this time no attempt is being made to separate the Lucien and Hayward members of the Garber, nor to map their respective outcrops. The upper limit of the Hayward sandstone member, which is also the top of the Garber sandstone and the base of the Hennessey, is the top of the highest sandstone bed of the member, the approximate outcrop of which, in Grant, Garfield, Kingfisher, Logan, and Oklahoma counties, is indicated on the map (Fig. 1). In northern Grant County the Hayward appears to lose its identity, chiefly on account of the thinning of the sandstone beds, so that in this region it is often difficult to differentiate this member from the Lucien or the Hennessey.

HENNESSEY SHALE

As in the case of Garber, the term "Hennessey" has been in common use for several years by geologists working in the red beds of northern Oklahoma. The name is from the town of Hennessey, in northern Kingfisher County, where the rocks are well exposed.

The Hennessey is throughout a clay-shale formation, and as such is easy to differentiate from the sub- and superjacent formations which consist chiefly of sandstone. Its lower limit is the heavy sandstone at the top of the Garber, and its upper limit the base of the Duncan sandstone.

The shales of the Hennessey differ from other red shales in the lower part of the Enid group in that they are rarely fissile or laminated, but are more commonly blocky and break with a conchoidal fracture having the appearance of "joint clay." The Hennessey as

a whole is also characterized by numerous bands or streaks, white or light green in color, varying in thickness from a few inches to 4 feet or more. These bands may be persistent for many miles and, in the absence of better material, serve as convenient data of reference for instrument work by geologists.

As in the case of the Garber, the Hennessey has also been divided by men familiar with its stratigraphy into lower and upper beds or members. For these members the authors here propose the names "Fairmont shale member" and "Bison banded member."

Fairmont shale member.—The lower 250 feet of the Hennessey shale is composed largely of deep-red clay-shale, not conspicuously laminated, but blocky and breaking with a characteristic conchoidal fracture. It has scattered thin white or greenish bands or streaks, rarely more than a few inches thick. The Fairmont is composed of alternating hard and soft layers, which weather into characteristic benches and shoulders, forming minor topographic features, which can be readily identified by those familiar with the stratigraphy of the region.

The name of the member is from Fairmont, a town in Garfield County, Oklahoma, near which good exposures of the shale occur.

The base of the member, which is also the base of the Hennessey shale, is placed at the top of the upper sandstone bed of the Hayward member of the Garber. The top of the Fairmont, in other words the separation between the Fairmont and the Bison, is not always easy to determine, but is usually placed at the point where the thick white streaks begin to appear.

Bison banded member.—The upper member of the Hennessey is named from Bison, a town in southern Garfield County, near which this phase of the Hennessey is well exposed. The town of Bison is built on a thin outlier of Duncan sandstone, but is surrounded on all sides by the Bison banded member of the Hennessey. The thickness of the Bison approximates 150 feet.

The Bison is composed largely of rusty-red, blocky, non-fissile clay-shales typical of the Hennessey. The distinguishing characteristic which justifies its differentiation as a member is the fact that it contains a considerable number of white or greenish bands or streaks of shale, here sandy, there calcareous. These bands or streaks are thicker and more numerous than those of the Fairmont member,

sometimes becoming as much as 3 to 4 feet thick. They may be very persistent and can be followed for several miles across the country, thus serving as good "markers" for instrument work.

The base of the member is placed at the lowest heavy white band of the Hennessey, which is not indicated on the map, and the top is the base of the Duncan sandstone.

DUNCAN SANDSTONES

In 1896 Cragin first described the Harper sandstone in Harper County, Kansas, as follows:

> The Harper sandstones . . . . comprise several hundred feet of more or less mottled, but prevailingly dull-red, or brownish-red, argillaceous and arenaceous shales and sandstones, above the Wellington shales and below the Salt Plain measures.[1]

The Harper sandstones of Kansas have been carried southward into Oklahoma, where they are found to constitute the formations which in this paper are called the "Garber sandstone," the "Hennessey shale," and the "Duncan sandstone." The uppermost of these formations, here called the Duncan, has been traced south as shown on the map (Fig. 1), crossing Grant, Garfield, Kingfisher, Canadian, and McLain counties, where it appears to be the same as the Duncan sandstone, which was described as follows: "The Duncan sandstone . . . . varies up to 250 feet in thickness, and consists of two or sometimes three ledges of heavy white or buff sandstone, sometimes dolomitic, separated by shales."[2]

The Duncan is further exposed around the periphery of the Anadarko Basin, circles the west end of the Wichita Mountain arch, and has been tentatively traced across Red River and is believed to connect with a sandstone which for several years has been known by the name "San Angelo formation."[3]

The authors have been in somewhat of a quandary regarding the choice of a name for this formation. For many years geologists in northern Oklahoma have used the name Harper to distinguish this sandstone formation lying above the Hennessey. However, since it appears that the so-called Harper of the Oklahoma geologists is only

[1] *Op. cit.*, p. 18.

[2] Charles N. Gould, "A New Classification of the Permian Red-Beds of Southwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8 (1924), pp. 322–41.

[3] Charles N. Gould, "The Correlation of the Permian of Kansas, Oklahoma, and Northern Texas," *ibid.*, Vol. 10 (1926), p. 151.

the middle and upper portions of Cragin's Harper sandstones, some other name must be employed. On account of the fact that the name San Angelo has priority over Duncan, it has been suggested that San Angelo be used, but in view of the fact that the exact equivalence of the two formations has not yet been definitely established we recommend that the name Duncan, rather than Harper or San Angelo, be used to apply to this formation in Oklahoma and Kansas.

As exposed in northern Oklahoma, the Duncan consists of rather soft, friable, or shaly, red sandstone. It is commonly cross-bedded, locally conglomeratic, and not uncommonly interstratified with red shales. This shaly phase of the Duncan has sometimes given rise to confusion regarding the location of the contact between the Duncan and the sub- and superjacent formations, and upon this subject the authors are not yet in complete agreement. The base of the Duncan is the line of contact between the lower sandstone bed and the top of upper blocky shale bed of the Hennessey. The top of the formation in some places is difficult to locate, on account of the gradual change of the sandy phase of the Duncan into the shale beds constituting the Chickasha, as will be set forth later.

The thickness of the Duncan appears to be variable, averaging perhaps 100–300 feet. Throughout its outcrop in Kansas and Oklahoma the Duncan is generally a persistent scarp-maker, forming a row of low hills overlooking the plain to the east, formed by the Hennessey shale and equivalent formations.

CHICKASHA FORMATION

This formation was named in 1924 from the town of Chickasha, county seat of Grady County, Oklahoma, to include the beds lying above the Duncan sandstone and below the horizon of the Blaine gypsum. The description follows:

> Near the southeastern end of the Anadarko Basin, the Chickasha formation is composed of about 175 feet of variegated sandstones and shales. On account of the predominating color of the rocks, the local name, "purple sandstone," has been used for this formation by geologists in this region. . . . . On passing north from the head of the Anardarko Basin the Chickasha rocks gradually change into brick-red shales which characterize the upper Enid. In southern Kansas Cragin named the rocks of approximately the same stratigraphic position the "Flowerpot shales." If, however, it proves feasible to connect the Duncan with the Harper, then the Chickasha will prove to be the stratigraphic equivalent of the Flowerpot, Cedar Hills, and Salt Plain Measures of Cragin. In the region extending along the base of the Gypsum Hills, from northwestern Canadian

County, northward to southern Kansas, the rocks of the Chickasha formation consist chiefly of bright red shales, with splotches and bands of white and green shale, and considerable amounts of gypsum, usually in the form of concretions, selenite, and satinspar. The Salt Plains of Blaine and Woodward counties (not to be confused with Cragin's Salt Plain measures) are located in this horizon.[1]

In northern Oklahoma the Chickasha is composed chiefly of gypsiferous red clay-shales and thin sandstones, the clays greatly predominating. The clays contain many bands or streaks from a few inches to several feet in thickness of white and light-green clay. The formation is also characterized by the great abundance of "polka-dot" balls, or concretions, of white and green clay, the origin of which has been the subject of much comment, but which is still obscure. The upper part of the Chickasha contains much satinspar, selenite, or concretions of gypsum.

As stated above, it is probable that the Chickasha includes the greater part of Cragin's Flowerpot shales, and probably also his Cedar Hills sandstone and Salt Plain measures. Upon this point, however, the authors are not in agreement. This being true, it is not now possible to draw a definite line between the Duncan and Chickasha in northern Oklahoma. Some geologists would include both the Salt Plain and Cedar Hills with the upper part of the Duncan. So far as we are aware the Cedar Hills sandstone of Kansas has not been found south of the Oklahoma line. This is in accord with Cragin's observations[2].

It is obvious that some additional work must be done on this problem in Alfalfa and Woods counties, Oklahoma, and Harper and Barber counties, Kansas. If the Flowerpot, Cedar Hills, and Salt Plain beds can be differentiated in northern Oklahoma they will logically constitute members of the Chickasha formation.

The upper limit of the Chickasha is the base of the Blaine gypsum of the Gypsum Hills. But, as stated many years ago: "The top of this formation [the Enid] is not a plane, since the gypsum beds, which mark its uppermost limits, are found to be more or less lenticular when traced for long distances."[3]

[1] Charles N. Gould, "A New Classification of the Permian Red-Beds of Southwestern Oklahoma," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 8 (1924), pp. 329–30.

[2] F. W. Cragin, "Observations on the Cimarron Series," *Amer. Geol.*, Vol. 19 (May, 1897), p. 363.

[3] Charles N. Gould, U. S. Geol. Survey *Water-Supply Paper No. 148*, p. 39.

OIL POSSIBILITIES OF THE BLACK HILLS REGION[1]

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INTRODUCTION

The Black Hills region is one of the most widely known parts of the United States. It has been studied by many geologists, and it is probable that little geological information can be added which will greatly benefit the oil industry. The most important publications are those of Darton, whose careful and accurate field work permits conclusions which are probably as nearly correct as can be obtained from surface observations. A great many wells have been drilled in the Black Hills region since Darton's last publication on the area, and a short history of this development with notes upon the results obtained and their bearing on future development and production will be offered here.

EARLIER DEVELOPMENT

The oil seepages at Newcastle and northeast of Moorcroft have been known for many years, the old settlers using the oil for axle grease and other purposes.

In the early days of Deadwood, oil for lubricating purposes was collected on springs near the town of Newcastle and shipped overland to Deadwood, but it was not until the early years of the twentieth century that the oil rush began. The first drilling was close to the seepages at Nwecastle, but no commercial wells were found. Four wells drilled on the flat southwest of Newcastle encountered only small shows of oil.

In the Butte field, 13 miles northeast of Moorcroft, five or six wells drilled half a mile down dip from the seepages were reported as making from 1 to 150 barrels per day. Judging from the report of men who worked here in the early days, some of the wells must have

[1] Paper read before the Association at the Denver meeting, October, 1922.

had a fairly large initial production, for they caused considerable excitement. However, the wells dropped off rapidly and enthusiasm soon began to lag. The oil discovered in the Butte field is a heavy, dark oil with practically no gasoline content. Since its discovery, drilling has been carried on in this field intermittently, but to date nothing has been done to change its status. The low grade of the oil makes it impossible to develop profitably.

In April, 1917, Norbeck and Nicholson drilled a well on Old Woman dome to the Minnelusa sand. According to reports the well made 200 barrels the first day, but production declined very rapidly and it was decided to drill deeper. Thirty feet lower another sand was encountered which made considerable water. Although the water sand was plugged off, the well never produced much oil. In a well drilled a mile farther south the sands were too tight to produce either oil or water, and the hole was abandoned. Subsequently, several wells have been drilled on Old Woman dome, but no oil in commercial quantities has been discovered.

The possibility of oil in the Black Hills did not attract much attention until the early part of 1919 when oil was discovered on the Mule Creek dome by the Ohio Oil Company. The interest thus stimulated brought a rush to the region. The Ohio company drilled the Dakota dome northeast of Moorcroft to the Madison limestone without any promising results, though oil is seeping from the Lakota sands on the south end of this structure. The Midwest Refining Company drilled the Dewey structure just north of Mule Creek to the Morrison shale and encountered water in all the sands. A little oil was discovered in the sandy horizon at the base of the Carlisle shales on the northwest nose of the North Upton anticline, known as the Thornton field, but deeper drilling was unsuccessful. About this time three or four wells drilled on the flank of the Rockyford anticline obtained a small production of heavy black oil in the Minnelusa sand. These wells did not produce enough oil, however, to justify drilling, and the field was abandoned. The Minnelusa is exposed on the crest of this structure. In the fall of 1919 interest began to lag, and it seemed likely that nothing more would be discovered in the Black Hills region.

LATER DEVELOPMENT

J. S. Adams located a well 3 miles from Osage just beyond the first terrace, and after encountering all the difficulties known to oil men, he finally, in March, 1920, struck the Newcastle sand from which oil went over the top of the mast. This well had a flush production of 150 barrels and held up to 100 barrels per day for three months. The oil is green and of very high grade, testing 42° Bé., with 31 per cent gasoline content. This discovery brought new activity to the Black Hills region and men hurried to Osage and Newcastle from all parts of the country. A drilling program was begun in Osage field in the summer of 1920, which was equaled only by Salt Creek. By fall the field was fairly well defined as most of the outside wells had been completed.

The main structural feature of the Osage field is a double-terrace structural nose. The lenticularity of the sand no doubt had much to do with the retention of the oil on these terraces after accumulation. The depth of the sand on the upper terrace is from 200 to 600 feet and on the lower terrace from 1,300 to 1,500 feet.

None of the wells have produced much oil and very little money has been made. On the other hand, not a great deal has been lost. The average daily production for the entire Osage field is about 400 barrels.

The discovery of the Osage field was more luck than good management, as the offset to the discovery well came in dry and all the other wells in the immediate vicinity were very small.

Other structures were later drilled. The Elk Basin Consolidated drilled the Seven Mile structure at Alzada, Montana, on the northeast flank of the Black Hills and found water in all the sands down to the Morrison formation. The well started about the horizon of the Greenhorn limestone. The Dutch Shell interests drilled the Colony structure, starting at about the base of the Mowry shale and drilling to the Minnelusa sand, where they got a strong flow of water. A well which was started in the Graneros shale east of Rocky Point on a large flat terrace encountered water in the Newcastle and Dakota sands. In the vicinity of St. Onge, on what is known as the St. Onge anticline, Norbeck and Nicholson drilled three wells in the summer of

1920, finding water in all three holes, though they claimed to have a show of gas at the top of the Newcastle sand. The anticline is faulted up on the north side and the Newcastle sand is exposed north of the fault. Therefore it does not seem that they had much chance of securing production from the Newcastle on this anticline. On the south side of the fault, the formations rise toward the Black Hills with no indication of closure above the Minnelusa sand. On the East St. Onge anticline, which opens into the Bear Butte structure where the top of the red beds are exposed, several water wells have been drilled at different times, but, aside from a small show of gas in the Newcastle horizon, nothing of importance has been discovered. These wells were all drilled to the Dakota and artesian water was secured.

Without success, the Julius Williams interests drilled wells at Fairburn, north of Hot Springs.

A small company drilled a well in the town of Ardmore, South Dakota, encountering no promising indications. Also, a well was drilled farther west on the same anticline, finding water in the Lakota. This anticline is one of the folds which form the south end of the Black Hills, opening toward the Black Hills without apparent closure. Three wells drilled on the Cottonwood anticline about 6 miles southeast of Edgemont did not strike oil. Two wells just outside of Edgemont on the same anticline got a show of oil in the Newcastle sand. This anticline opens toward the Black Hills without closure. The Carter Oil Company drilled a well 16 miles south of Newcastle on Beaver Creek, encountering water in all the sands down to the Lakota. The Skull Creek Syndicate drilled a well on the NW. $\frac{1}{4}$ Sec. 16, T. 44 N., R. 62 W., to 3,700 feet with a show of oil in the Newcastle sand and water in the Dakota and Lakota sands. The Bachelor Oil Company is drilling (October, 1922) a well in Sec. 21, T. 45 N., R. 63 W. The Producers and Refiners are starting a hole on the North Upton dome to test the Minnelusa sand. A 1,600-foot hole had previously been drilled on this structure, testing everything but the Minnelusa sand. The Union Oil Company drilled a well south of Upton on the flank of the Black Hills to the Minnelusa and encountered water in all the sands.

Both the Midwest Refining Company and the Union Oil Company drilled wells on the South Upton dome to below the Dakota sandstone without encouraging results.

A small company organized by Mr. Brown in Rapid City drilled a well on the Bear Butte structure to the Minnelusa sand, which produced water. Bear Butte is an igneous intrusion on the side of the Bear Butte dome, but it does not cut through the high point of structure. It appears to be a question whether this well ever had a chance of production. A few wells which were drilled to the Newcastle sand on the terrace at Poison Creek, 25 miles northeast of Moorcroft, secured a little oil, but not enough to make the wells commercial.

When we look back over the development in the Black Hills area and consider all the wells which have been drilled and the large number of small structures which have been tested with unsatisfactory results, we realize that it takes courage to undertake to find anything worthy of testing. For the future, in the Black Hills region we may count on production from Osage and Mule Creek, providing the price of oil advances enough to justify pumping and drilling.

There are about 5,000 acres of proven land in the Osage field where wells will produce from 1,000 to 5,000 barrels during their lifetime. If the royalty which it is necessary to pay in this field could be reduced and the price of oil increased, the writer believes that it would be possible to put the field on a paying basis.

Mule Creek has approximately 1,000 acres of proven land which, no doubt, will yield 3,000 barrels per acre. The Mule Creek oil is a dark, low-grade oil with some asphalt content. It tested about 31° Bé., and is worth a little more than half the price of Osage crude. The wells at Mule Creek make from 10 to 50 barrels a day, and by careful handling the field can be put on a paying basis.

The chance of discovering new fields in the Black Hills district is limited to comparatively small areas, though several structures have a possibility of black oil in the Minnelusa horizon. A few, with structural features similar to the Osage field, have a chance of production in the Newcastle sand. In addition, several folds are known where as yet it has not been possible to prove closure.

SAND CONDITIONS

The most important question with reference to the future oil possibilities of the Black Hills area is that of the sand conditions. A short description of each sand is therefore given.

The Minnelusa sand occurs just above the Pahasapa limestone and varies in thickness from 400 to 800 feet. This sand when seen on the outcrop always shows 50 to 100 feet of sugary sand which is very porous, and it would appear to be a good oil reservoir. However, this appearance may be caused by weathering, as suggested by Darton in the Newcastle Folio. In the diamond drill hole at Cambria, reported by Darton, the Minnelusa sand was so thoroughly cemented that it would not permit the passage of water. The well at Edgemont got very little water from the Minnelusa horizon.

In examining many outcrops of the Minnelusa sand in the Black Hills, the writer has found it saturated with oil at only one place, Rockyford. In several places where it seemed that the sand should be saturated there was no indication of oil. It appears that wells drilled to the Minnelusa sand at the proper location have a chance of obtaining production.

At the base of the Sundance or top of the red beds, is a good porous sand from 30 to 50 feet thick, which if drilled under the proper conditions, might produce considerable oil. This sand has been drilled by the Ohio on the Dakota dome, by the Dutch Shell at Colony, and by Norbeck and Nicholson at Old Woman Creek.

The Lakota sandstone series is approximately 100 feet thick and contains generally a sandstone member of 60 feet near the top. This sandstone varies from massive to thin-bedded and platy. The only place where the Lakota sand has proven productive in the Black Hills region is at Mule Creek. Oil is seeping from the Lakota sand on the south end of the Dakota dome, near Moorcroft. The Lakota has oil possibilities providing it is tested on a structure with considerable closure, but the porosity of the sandstone is so high that it gives good access to all moving waters, and on structures of small closure or on terraces similar to Osage one cannot expect to encounter production in the Lakota.

The Dakota is a very porous sandstone which carries fresh water wherever it has been drilled in the Black Hills area, but in most of

the places where it has been tested the structures are either terraces or structures with small or doubtful closure. It is very probable that if this sandstone were drilled under proper conditions it might be productive. The Dakota produces oil in Lance Creek and Big Muddy and is saturated at Salt Creek.

The Newcastle sandstone, which occupies the horizon at the base of the Mowry shales, is very irregular in character. At Clifton Siding the sand is approximately 30 feet thick. It thins to the south very rapidly, and at Edgemont, South Dakota, it is only one foot thick. North from Clifton Siding the sand increases in thickness as far as Newcastle, where it is from 30 to 40 feet thick. Thence, it thins very rapidly northward, and on the outcrop at Osage it consists of two sand members about 18 inches thick. In the Osage field this sand ranges in thickness up to 10 feet. North of Osage the Newcastle sand is comparatively thin to the Belle Fourche River, beyond which it increases in thickness to about 20 feet at the Butte field. Here two oil seepages occur at the outcrop of the sand, at the farther north one of which a pit has been sunk crosscutting the sand. It appears that the oil is coming from a 1-foot layer at the bottom, but at the outcrop there seems to be no reason why the entire thickness should not be saturated. No doubt it is due to a local hardening of the middle bed. If one could crosscut this sand a few hundred feet from the outcrop it would be possible to learn, perhaps, the reason for the non-productive character of the middle bed.

North of the Butte field the sand thins again and there is very little sand at this horizon until one reaches the Little Missouri, where from 10 to 20 feet of good sand is exposed along the bank of the stream. At the extreme northwest end of the Black Hills the sand disappears and is represented by only a hard sandy shell about 1 foot thick.

On the east side of the Black Hills the Newcastle sand is of considerable thickness at a few places, but for the most part it is represented by a 1-foot bed of quartzitic sandstone and a few feet of sandy shale. A few seepages have been reported in the Newcastle sand on the east side of the Hills, but the writer has never had the satisfaction of seeing one, though he has visited several places where the oil was supposed to be seeping from this horizon.

On the west side of the Hills the Newcastle horizon contains oil wherever there has been a chance for accumulation, but the amount depends upon the thickness of the sand. With 2 feet of sand a well is small, with 20 feet the well is large. A great deal of work has been done in the effort to determine why the Newcastle sand is thick in some places and thin in others, but it has not been possible to reach conclusions which permit explanation of the thickness of the Newcastle sand at any given place. The only way one can tell whether a well in the Newcastle sand will be successful is to drill it. The Newcastle sand has the largest possibilities, the writer believes, of any sand in the Black Hills region. Probably there will be no phenomenal wells in the region, but wells good for 10 to 100 barrels per day will be found. If the price of oil rises to a reasonable figure, a great deal of the shallow territory along the west flank of the Black Hills can be operated at a profit.

The Carlisle sandstone member in the Black Hills area corresponds to the First Wall Creek sand at Big Muddy. This sandstone horizon in the Black Hills is very shaly, and in most places it contains very little sand, but in other places it contains lenticular sandstone members which range in thickness from 10 to 30 feet. There is more sand at this horizon from Clifton Siding to Osage than in any other part of the Black Hills area, although there is a well-developed sandstone just north of Ardmore and a bed of coarse conglomeratic sandstone in the Butte field northeast of Moorcroft.

The only place at which this horizon produces oil is at Thornton where fourteen wells have been drilled. These wells flushed from 10 to 50 barrels but soon dropped off, owing to the cavy material which makes up this horizon. Within a month the wells were making no more than 1 barrel per day. To date, no method of keeping this fine sand out of the tubing has been devised, and the wells accordingly need constant care. So far as the writer knows, the only well which ever paid for itself in this field is No. 3 of the Idaho-Wyoming Oil Company. A great deal of money was spent in the field to see if it could not be placed on a paying basis, but in 1921 when the price of oil dropped, the field was abandoned.

Some of the wells drilled through the Frontier horizon in the vicinity of Newcastle report from 50 to 70 feet of sand, but the sand

is so well cemented and hardened that it is almost dry. The Carter Oil Company on Beaver Creek report a sand making perhaps 1 barrel of water per hour. The well drilled by E. T. Williams 6 miles southwest of Newcastle found the sand dry. This Frontier horizon does not seem to have many oil possibilities in the Black Hills region, for the sand is either missing or too tight to form a good reservoir.

The next sandstone above the Frontier sands is the Fox Hills sandstone, about 3,000 feet higher stratigraphically. This sandstone, which is approximately 200 feet thick, is composed of thin-bedded sandstone interbedded with sandy shale. As the sand has been eroded from nearly all of the Black Hills area, this horizon can be eliminated from any future consideration.

CONCLUSION

Considering the results of the development work which has been done in the Black Hills region, it does not seem possible that anything in the future will be found to change the outlook. Most of the favorable anticlines along the Black Hills have been eroded to such a depth that there is nothing left to test but the Minnelusa sand. The time has not been reached when the development of much black oil in the state of Wyoming may be undertaken, for at present it is impossible to sell the by-products. Terraces which have a chance of production in the Newcastle sand will no doubt be developed as soon as the price of oil will justify it. Very few untested structures in the Black Hills area have a chance of production in the Lakota sand. The big possibilities in the Lakota lie to the west, in the big basin, where folds may have been covered by Fort Union and lower Tertiary deposits.

The Sundance sand may produce some oil in this area, but we have no information to justify this opinion except that a little gas was struck in this horizon in the test on Old Woman Creek dome.

From information available at present, it does not seem probable that any phenomenal fields will be opened in the Black Hills region, although a few undeveloped possibilities remain. The writer feels certain that, by dint of careful management and economical methods, the Black Hills regions will produce a great deal of oil from small wells.

DISCUSSION

WALTER STALDER: Is the Osage field drilled on a closed fold?

MR. SINCLAIR: That is an expression that I have been seeking from a Rocky Mountain geologist for some time, namely, that it is not necessary to have a closed fold in order to get production in this region.

About the Black Hills are a number of anticlinal noses and other structures of a type that are productive in other parts of the country; for example, terrace structures have been found productive in the Mid-Continent fields, anticlinal noses are productive in other regions, and we have also learned at this meeting that even faulting sometimes favors concentration. Why should it not be possible to get production under similar conditions about the Black Hills and in Rocky Mountain areas? Why rely, therefore, only on dome structures?

My observation in the region flanking the Black Hills is that water sands frequently occur close to the oil sands and that most operators have been very careless in drilling through oil sands and into water sands, or through water sands and into oil sands without properly shutting off water. Cementing has very rarely been tried. It is my impression that when this region receives the attention of operators who are thoroughly familiar with cementing operations and who will carefully put the same into practice, some areas which at present have a "black eye" will have a good chance of being redeemed.

In answering the remarks of Mr. Stalder I would state that it was my impression that this question had been answered in the report, but in case it was not brought out in sufficient detail, I wish to emphasize that all monoclines, all truncated anticlines, all terraces that have any chance of being productive have been drilled in the Black Hills region.

It may be possible that some of the wells have been ruined by permitting water to enter the oil sand, but in most cases the Newcastle sand is the only sand that has produced any oil in commercial quantities in the Black Hills region, and very little water is encountered above this sand, so the water problems have been few and are not at all complicated.

In my opinion we will not be able to increase the productive area of the Black Hills by more efficient cementing methods, but no doubt the production will be increased by more efficient recovery methods.

GEOLOGICAL NOTES

FORT SCOTT–WETUMKA CORRELATION

The Fort Scott limestone of the Kansas section, the most important stratigraphic horizon in the Pennsylvanian, had in 1910 been tentatively correlated with the Calvin sandstone of the Coalgate folio.[1] In 1917 the writer stated that the equivalent of the Fort Scott reaches higher up in the southern section.[2] The new geological map of Oklahoma (in print by the U. S. Geol. Survey) made it necessary to approach the question again.

The Wetumka shale or, to be more accurate, the basal sandstone of the Wewoka formation and the top ledge of the Calvin sandstone were traced by R. W. Clark and the writer as far north as Deep Fork Canadian River and the top of the Calvin as far as the Okmulgee Mission. The Wetumka decreases in thickness from a wide shale flat near the town of Wetumka to an ordinary shale interval between sandstones southwest of Weleetka. This had been overlooked before and the wide shale outcrop of Tiger Flats had erroneously been correlated with the Wetumka.[3]

The base of the Calvin is present in the escarpment southwest of Dustin. The writer has noticed a tendency of the lower ledges to leave the escarpment and to extend into the flat, but not enough time was available for careful mapping. Therefore the first heavy sandstone above the Henryetta coal was assumed to be the base of the Calvin. Thus the Calvin is represented at Okmulgee by a distinct sandstone ledge near the Mission, a shale interval and a lower shaly sandstone exposed on the highway about one mile to the east. These two ledges could not be traced continuously northeastward, but an escarpment southwest of Bald Hill is their equivalent. This escarpment cannot be traced quite as far as the village of Bald Hill, but a little farther northeast a sandstone ledge can again be observed at this horizon a little above the limestone exposed east of Bald Hill. The Calvin sandstone loses its identity at the foot of

[1] Charles N. Gould, D. W. Ohern and L. L. Hutchison, *State University of Oklahoma Bull. 3.*

[2] Edward Bloesch, "North-South Correlation of the Pennsylvanian of Oklahoma," *Southwestern (Amer.) Assoc. Petroleum Geologists' Bull.*, Vol. 1 (1917), pp. 134–35.

[3] R. W. Clark and C. Max Bauer, "Notes on Geology of the Okmulgee District," *Amer. Assoc. Petrol. Geol. Bull.*, Vol. 5 (1921), p. 285.

Concharty Mountain and H. D. Miser and the writer, who traced these formations from Okmulgee northward, have not attempted to identify the Calvin near the Arkansas River.

The base of the Wewoka south of Deep Fork Canadian River can with reasonable accuracy be correlated with a sandstone escarpment about two miles north of Okmulgee, which extends to Bald Hill forming the Twins. Farther north higher sandstone ledges coming in from the west join with it and form Concharty Mountain, but the basal Wewoka ledge can be traced to where this plateau drops off to the Arkansas River. There it is underlain by a section containing several ledges of limestone. No place was seen where a full section is exposed and no measurements were taken, as on the steep slope some exposures may be out of place. There is an upper limestone ledge of at least six feet in thickness and more limestone lower down. In one place black shale was observed. Around the north end of the hill farther west a lower limestone, separated from the upper series by sandstone, is exposed. This limestone series, which can be traced northwestward to Wealaka Mission, is the equivalent of the Fort Scott limestone, but the lowest ledge mentioned may be lower, equivalent to what Ohern includes with the Fort Scott in his Claremore formation. The nature of the limestones differs considerably from the Fort Scott east of Broken Arrow. It is more yellow or brownish and shaly in part. In one place chert concretions were found. The fossils are mostly crinoids and bryozoans, in short it is a facies well known in Oklahoma where limestones begin to disappear. This limestone series can be traced southward along Concharty Mountain and is well exposed on the north line of Sec. 35, T. 16 N., R. 14 E., but disappears beyond. In the Twins it is probably represented by limy sandstone and north of Bald Hill chert concretions were found, considered to be the equivalent of the chert layer mentioned near the Arkansas River.

The top of the Fort Scott is therefore practically the top of the Wetumka, the limestone being separated from the basal Wewoka sandstone by only a few feet of shale. The base of the Fort Scott is probably equivalent to the base of the Wetumka, but may be slightly higher. All of the Calvin belongs to the Cherokee shale. The correlation of the Fort Scott with the Wetumka, as assumed on the new Oklahoma map and published by C. N. Gould,[1] is practically certain and may be subject to only very slight changes.

EDWARD BLOESCH

[1] Charles N. Gould, "Index to the Stratigraphy of Oklahoma," *Oklahoma Geol. Surv. Bull. 35*, 1925.

COMBINED GEOLOGIC AND OIL-AND-GAS MAP OF WYOMING

The U. S. Geological Survey has revised the information on the oil and gas map of Wyoming (preparatory to publishing a new edition of that map), and, as an experiment, has recently printed a small stock of combination maps—the colors for oil and gas fields and pipelines being overprinted on the colored geologic map of Wyoming.

These combination maps may be of use to geologists interested in Wyoming, and copies may be obtained from the Survey (price $2 each) as long as the stock lasts.

NOTES ON THE AGE AND CORRELATION OF THE MORENO SHALE

On the west side of San Joaquin Valley, California, extending from near Mount Diablo south almost to Coalinga in Fresno County, is an almost continuous outcrop of a body of shale which has very definite characteristics. Lithologically it most resembles certain Tertiary formations in the State and for a long time was referred to the Eocene.[1] It was not until 1915 that its age was definitely fixed as Upper Cretaceous by Anderson and Pack and the name "Moreno Shale" given to it.

The type locality of the formation is Moreno Gulch, a small wash extending westward through the Panoche Hills. In reading Anderson and Pack's account one is impressed particularly by the repeated statements that this shale is diatomaceous, together with the proof offered that it is of Cretaceous age.

The presence of fossil diatoms in rocks of Tertiary age in a great many localities and the apparent lack of evidence for the occurrence in Cretaceous rocks has given rise to the belief that these organisms originated at the close of the Cretaceous. The literature contains many statements such as the following made in 1896 by Van Heurck, the foremost authority on the group at the time:

> Deposits of fossil diatoms are numerous and are found in very various localities. The most ancient is that found in 1878 by Mr. Shrubsole, of Sheerness-on Sea, in the London Clay, which belongs to the Lower Eocene (Tertiary period).[2]

[1] See Anderson and Pack, *U. S. Geol. Survey Bull. 603* (1915), pp. 49–50, for references to the earlier literature on the subject.

[2] Henri van Heurck, *A Treatise on the Diatomaceae*, translated by W. E. Baxter, 558 pages, over 2000 figures. London, 1896.

Numerous reports of diatoms existing in formations older than Tertiary have been made in the past but whenever these have been investigated by competent microscopists something has always been found to cast doubt on the matter. Sometimes radiolarians were mistaken for diatoms; again the collections were made in such a place as to have become contaminated with living species.

In view of this situation in the literature the record of Anderson and Pack of diatoms in undoubted Cretaceous shales in San Joaquin Valley was looked at askance. In September 1925, in company with Mr. H. J. Steiny, the writers visited the type locality of the Moreno shale for the express purpose of investigating its microscopical contents and checking the observations of Anderson and Pack. Their observations were definitely confirmed. The Moreno shale is unquestionably Upper Cretaceous in age as shown by fossil *Bacculites* and *Hamites* found in place. Likewise, it contains fossil diatoms in place. This fact is well worth considerable attention from geologists because it cannot now be said that because of the presence of these organisms a rock is necessarily Tertiary in age.

The section of shales exposed in Moreno Gulch was studied in some detail and collections were made about every 10 feet far downward from the contact with what has been called Eocene sandstsone at the top into the shales where organisms of any kind are very scarce. The upper 200 feet of the exposure was found to be a dark brown clay shale with much organic matter but very few fossils. This gave way gradually to a light buff-colored shale about 200 feet thick which in its most fossiliferous part contained great numbers of impressions of foraminifers chiefly belonging to the genus *Siphogenerina*. The calcareous tests of the fossils have been completely dissolved away.

This light-colored zone is undoubtedly one of the "few small areas" stated by Anderson and Pack to be "pure white, diatomaceous shale like that in the Tertiary." Some thin layers were found to be white and the weathered exposures would be thus generally described. Upon digging into the shale body, however, even the lightest is distinctly buff or brown in color. It is this zone that contains diatoms. The siliceous frustules of the organisms were found unchanged and distributed rather uniformly through the mass of shale. Those thus far segregated from the matrix belong to the genera *Coscinodiscus*, *Craspedodiscus*, *Melosira*, *Stephanopyxis*, and some others. A few radiolarians were found but they have not been identified. None of the species of diatoms are the same as occur in the well-known Miocene shales of California, usually referred to as "Monterey Shale." In fact, all the species seen appear to be undescribed

and unfigured, although this statement must be qualified because the genera *Melosira* and *Stephanopyxis* are relatively simple in structure and possess few characters for discrimination. This layer passes downward gradually, into dark earthy clay shales which are almost barren of fossils. A critical study of the flora of the deposit will be made at as early a date as possible and its relation to other known deposits will then be made known.

J. A. TAFF AND G. D. HANNA

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APPOINTMENT OF BUSINESS MANAGER

The Association in General Assembly at the Annual Meeting in Dallas, Texas, March 27, 1926, passed a resolution stating, "that the incoming executive committee and its successors be and they are hereby empowered and instructed to select and employ, whenever such action can be initiated without increase of membership dues, a full-time business manager, not a member of the executive committee, who shall carry on, under the direction of the committee, the secretarial and editorial work of the Association and such other work as in the committee's opinion properly may be assigned to him; and the committee is further empowered and instructed to fix and establish headquarters at which such work shall be performed."

The present executive committee after due consideration of this matter has appointed Mr. J. P. D. Hull Business Manager of the Association and selected Tulsa, Oklahoma, as headquarters of the Association. The offices of the Association are located at 224 South Cheyenne Avenue, Tulsa, Oklahoma.

ALEX W. MCCOY

COMMITTEES FOR THE AUTUMN MEETINGS OF THE ASSOCIATION

For the joint meeting of the American Association of Petroleum Geologists with the American Mining Congress and the American Institute of Mining and Metallurgical Engineers to be held at Denver, Colorado, on September 20–24, 1926, the following committee has been named:

General Chairman:	Charles M. Rath, Midwest Refining Company, Denver, Colorado
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	E. Walter Krampert

Entertainment: E. Russell Lloyd, *Chairman*
Harold W. Lowrie
Paul B. Whitney
Mrs. Thomas S. Harrison

For the New York City Meeting to be held during October or November, 1926, at dates to be announced later, the committee is:

General Chairman: Everett DeGolyer
W. B. Heroy
L. C. Snider
C. H. Wegemann
C. W. Washburn

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

L. S. HARLOWE has been appointed chief geologist of the Louisiana Oil Refining Corporation at Shreveport, Louisiana, effective July 1.

M. E. WILSON, manager of the producing department of the Louisiana Oil Refining Corporation, at Shreveport, Louisiana, spent the last week of June with his family at Bella Vista, Arkansas.

HAROLD VANDERPOOL, of Norman, Oklahoma, is now in the geological department of the Humble Oil and Refining Company at Shreveport, Louisiana.

J. P. SMITH, formerly in the geological department of the Ohio Oil Company at Shreveport, Louisiana, has completed a year of postgraduate work on sedimentary problems at Leland Stanford Junior University, California.

W. ARMSTRONG PRICE, consulting geologist, who has recently moved his office to the Bankers' Mortgage Building in Houston, Texas, is making a geological study for C. A. and Gene L. Wright, of Chicago, of their operations and holdings in the vicinity of Edna, Jackson County, Texas.

EARL A. TRAGER has severed his relations with the Research Department of the Marland Oil Company to become associated with the firm of petroleum engineers which is being organized by Earl Oliver, to be known as Earl Oliver & Company. His headquarters will be in Ponca City, Oklahoma.

Word has been received of the death of MR. JAMES V. HOWE, of San Antonio, Texas. Mr. Howe was a full member of the Association.

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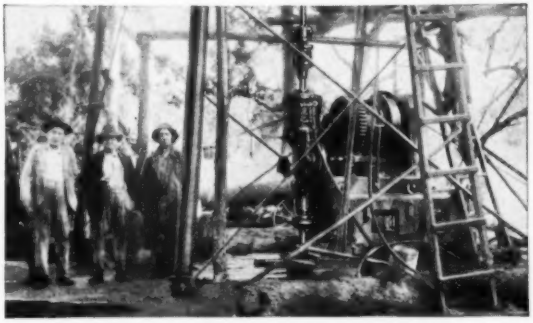

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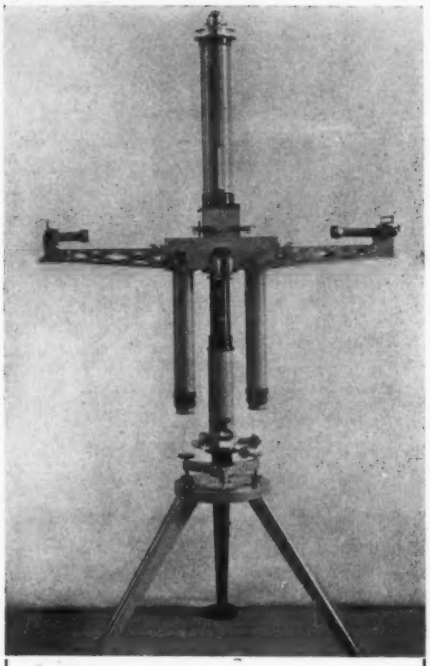

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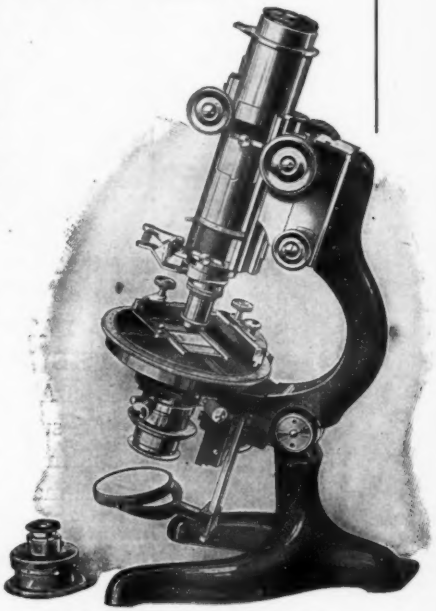

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THE PACIFIC SECTION

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MEMBERSHIP

Membership in the Pacific Section is restricted to members of the A.A.P.G. in good standing, residing in the Pacific Coast States. Dues of $2.00 per year are payable to the Secretary-Treasurer of the Pacific Coast Section. Members of the A.A.P.G. transferring to the Pacific Coast are cordially invited to become affiliated with the local section, and to communicate their change of address promptly to the Secretary-Treasurer of the Pacific Section.